SUMMER FALLOW in THE WESTERN UNITED STATES

Conservation Research Report No. 17

Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

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PREFACE

This publication summarizes available information on summer fallow. Advantages and disadvantages of summer fallow as a management practice are presented with principal reference to crop yield and soil and water conservation in the 17 Western States.

For ease and convenience of discussion, the 17 Western States are divided into five major regions: northern Great Plains, central Great Plains, southern Great Plains, the Northwest, and the Southwest. The northern Great Plains is subdivided with respect to spring wheat and winter wheat.

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Italic numbers in parentheses refer to Literature Cited at the end of each chapter.

CHAPTER 1.—INTRODUCTION

H. J. Haas, W. O. Willis and J. J. Bond [1]

In the dryland region of the 17 Western States, low precipitation usually limits crop production, and summer fallowing is often practiced to increase the water available for succeeding crop growth. In this publication, summer fallow is defined as a farming practice wherein no crop is grown and all plant growth is controlled by cultivation or chemicals during a season when a crop might normally be grown. Thus, production for one season is forfeited in anticipation that there will be at least partial compensation by increased crop production the next season.

Summer fallowing has been a controversial practice in some regions since its inception the latter part of the 19th century (*3*, *7*). Proponents of the practice have emphasized the water-conserving, weed-controlling, and crop-yield-stabilizing virtues, whereas critics have emphasized the inefficiency in soil-water storage and the wind- and water-erosion problems associated with fallow. Despite the criticism, the acreage of summer fallow has steadily increased since 1910 (fig. 1.1), until there were about 37 million acres in 1967 west of the Mississippi River (*2*). Nearly all this fallow acreage is in the 17 Western States (*9*).

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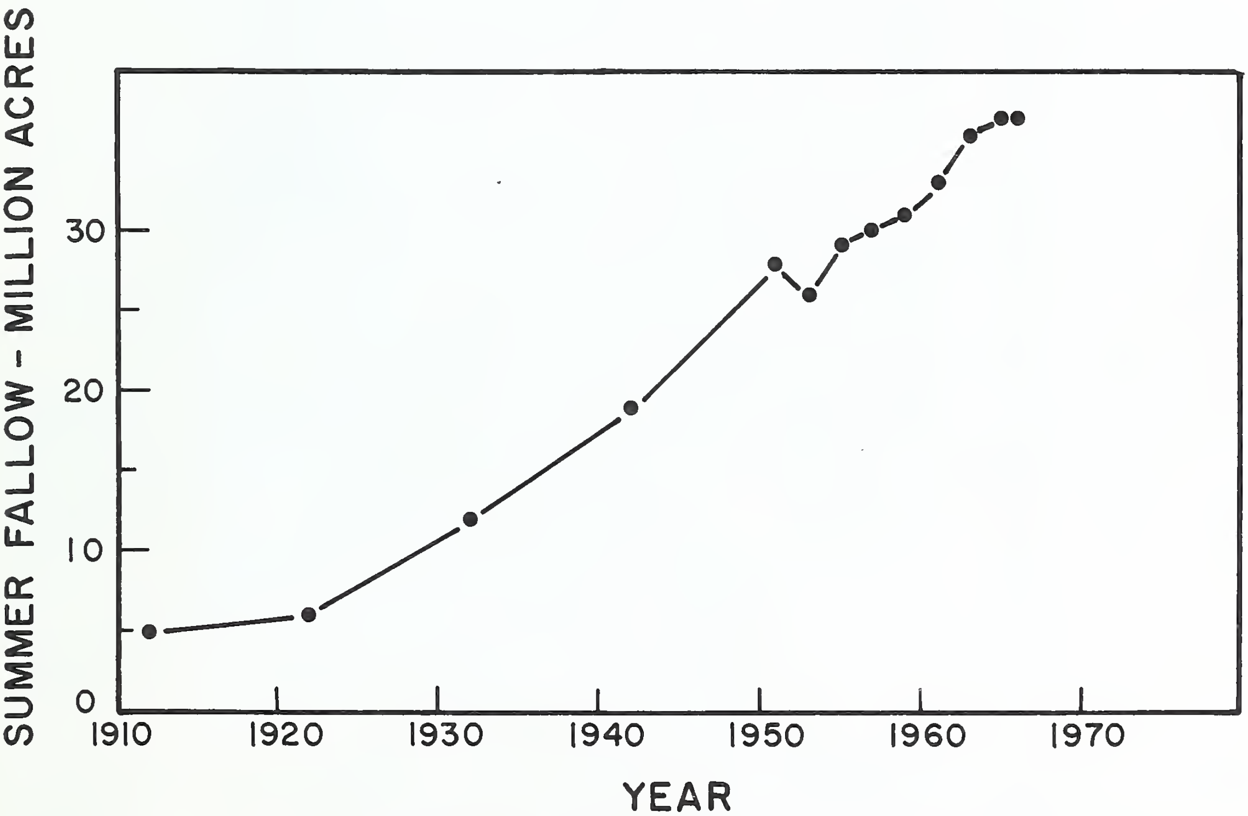

FIGURE 1.1—Increase in summer-fallow acreage west of the Mississippi River (*2*).

Apparently, farmers have believed that summer fallow is beneficial, at least for their immediate benefit. Mathews (*4*) discussed some of the reasons why summer fallow is or should be practiced:

> The extent to which it (summer fallow) is used or should be used depends on its effect on the quantity, economy, and stability of production, and other factors. These are in turn affected by other considerations, such as the kind of crops grown, the competition afforded by replacement crops, the type of farming practiced, the weed control needed and afforded, erosion hazards, and the ultimate effect on the soil. The fallow acreage may also be changed by forced adjustments in cropping practices brought about by acreage controls and by the relation between production costs and crop prices. Fallowing enables a farmer to operate nearly twice the acreage of land without additional equipment.

The distribution of fallow acreage in the 17 Western States (northern Great Plains, central Great Plains, southern Great Plains, Northwest, and Southwest) in 1964 is shown in figures 1.2.1 to 1.2.5. The numbers represent thousands of acres of fallow in each county with more than 500 acres of fallow (*9*). Fallow-acreage concentrations include southeastern Washington, north-central Oregon, southeastern Idaho, the Utah Panhandle, northern and south-central Montana, most of North Dakota, central South Dakota, western and southern Nebraska, eastern Colorado, western Kansas, the Oklahoma Panhandle, part of the Texas Panhandle, and west-central California.

Most of the soils fallowed belong to the order Mollisols (*10*). Suborders included under the Mollisols are the cool, moist Borolls (formerly Chernozem and Chestnut soils); the warm, dry Ustolls (formerly Chernozem, Chestnut, Reddish Chestnut, and some Brown soils); and the warm, dry Xerolls (formerly Chestnut and Brown soils). A small part of the fallowed soils belong to the order Entisols, suborder Orthents (formerly Brown soils).

Summer fallowing is being practiced in areas receiving 20 inches or less of precipitation, although there are sizable acreages of fallow in areas such as the central Great Plains (fig. 1.2.2) where precipitation is as much as 28 inches (fig. 1.3). Mean annual precipitation (isohyetal) lines are shown in figure 1.3. In the Great Plains, a summer-rainfall type prevails with about 75 percent of the annual precipitation occurring during the months of April through September. Because of higher evaporation rates in the southern Plains (fig. 1.4), the effectiveness of precipitation is less there than in the northern Great Plains. As early as 1910, Briggs and Belz (*1*) reported that for every 3-inch increase in pan evaporation an additional 1 inch in precipitation is required for equal plant growth. Thus, if evaporation in Texas is 21 inches higher than in North Dakota and Montana, then 7 inches more precipitation would be required in Texas to be equivalent to precipitation in North Dakota and Montana. The efficiency in water storage under fallow also decreases from north to south (*5*).

Farther west, and in the intermountain regions, a winter-type precipitation prevails. Precipitation falls during the cooler months and soil-water storage efficiencies for fallow are higher than under the summer-rainfall type (*4*).

Wheat is the crop most widely grown in the 17 Western States, particularly on fallow. Major areas of winter and spring wheat production are shown in figures 1.5 and 1.6, respectively. Other small grains such as barley (fig. 1.7), oats, rye, and flax are grown to a lesser extent. Of the row crops, corn is grown primarily in the northern and central Great Plains, sorghum in the central and southern Great Plains, and cotton in the southern Great Plains only. Field peas are relatively common in the Pacific Northwest.

Alternate cropping and fallowing is usually practiced in the drier regions, but under higher rainfall conditions other crop sequences are sometimes followed. In the northern Great Plains, corn is often followed by 1 or 2 years of small grains or fallow may be used in place of corn. In the central and southern Great Plains, a rotation of fallow-wheat-sorghum is often used. In the Northwest, field peas are often rotated with wheat.

A number of research reports have been written regarding the merits of summer fallow, but Mathews' publication (*4*) is the most comprehensive. Since these articles were written, much additional data have been obtained. The purpose of this publication is to summarize the available information regarding summer fallow and to present the advantages and disadvantages of fallowing with regard to crop yield and soil and water conservation. Fallow also affects air and water pollution and wildlife habitat (*6*, *8*). These subjects, although of immediate concern, are not discussed.

For ease and convenience of discussion, the 17 Western States are divided into five major regions as shown in figure 1.8. Spring and winter wheat in the northern Great Plains are discussed in separate chapters.

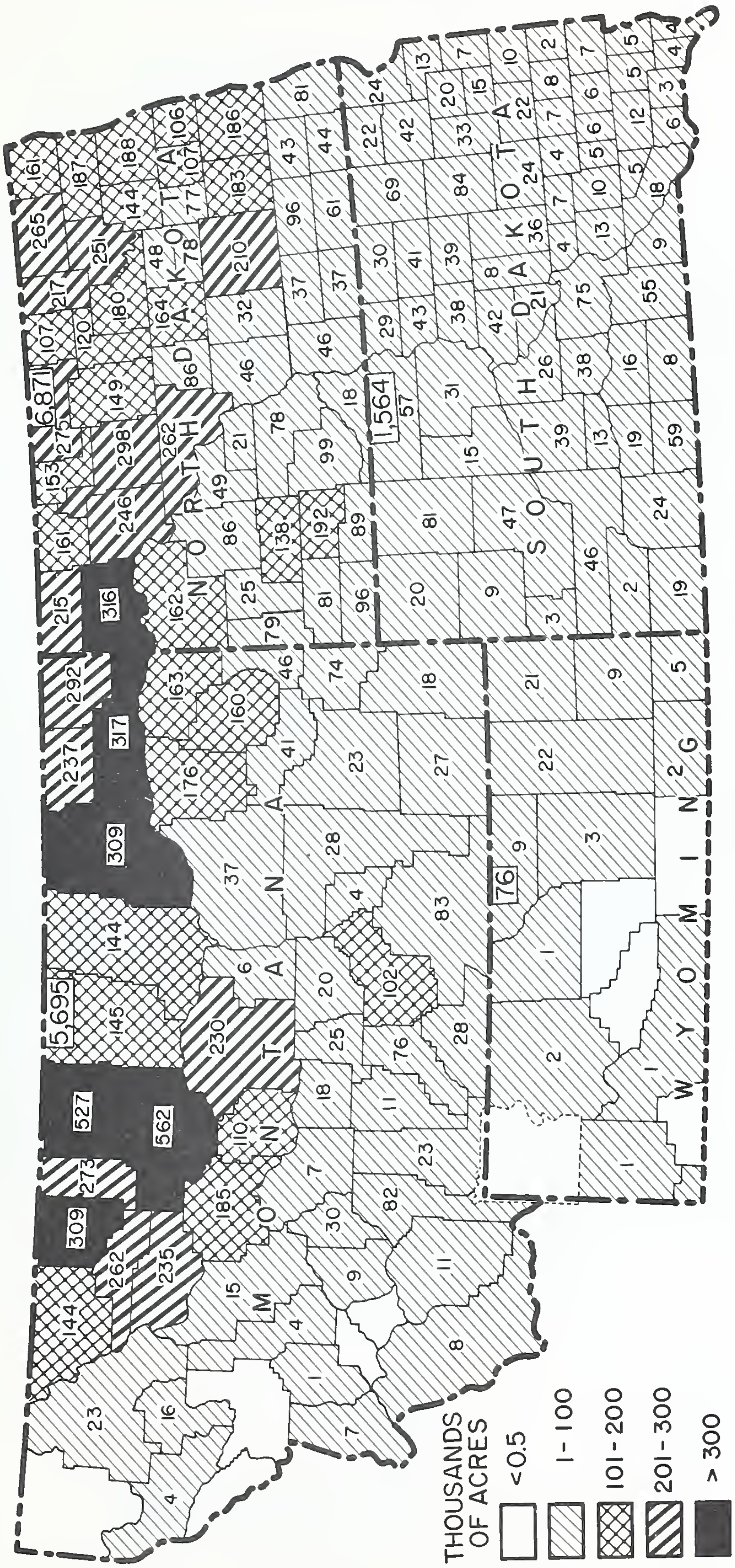

FIGURE 1.2.1.—Thousands of acres of summer fallow in each county of the northern Great Plains (counties with 500 acres or less of fallow are blank) (9).

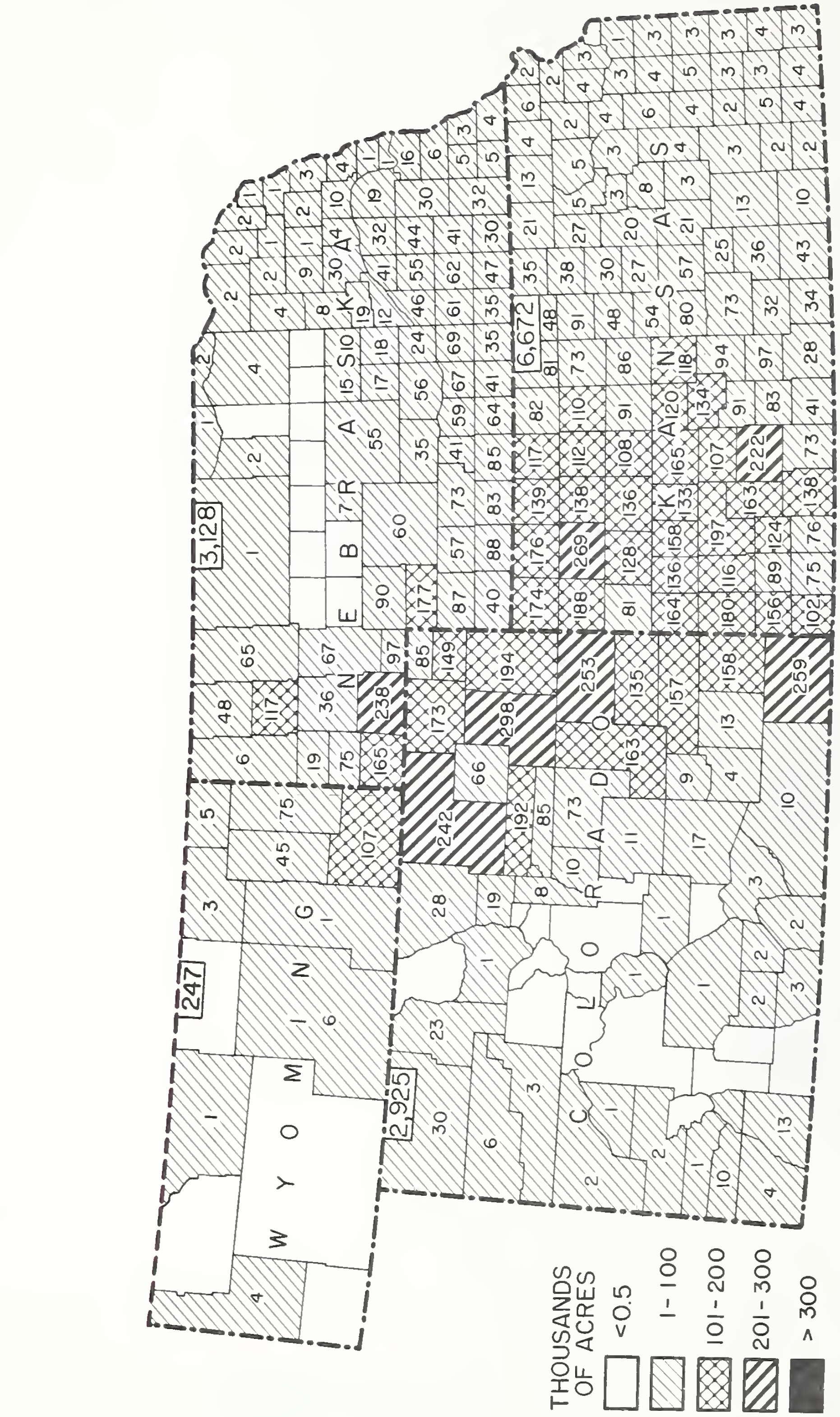

FIGURE 1.2.2.—Thousands of acres of summer fallow in each county of the central Great Plains (counties with 500 acres or less of fallow are blank) (9).

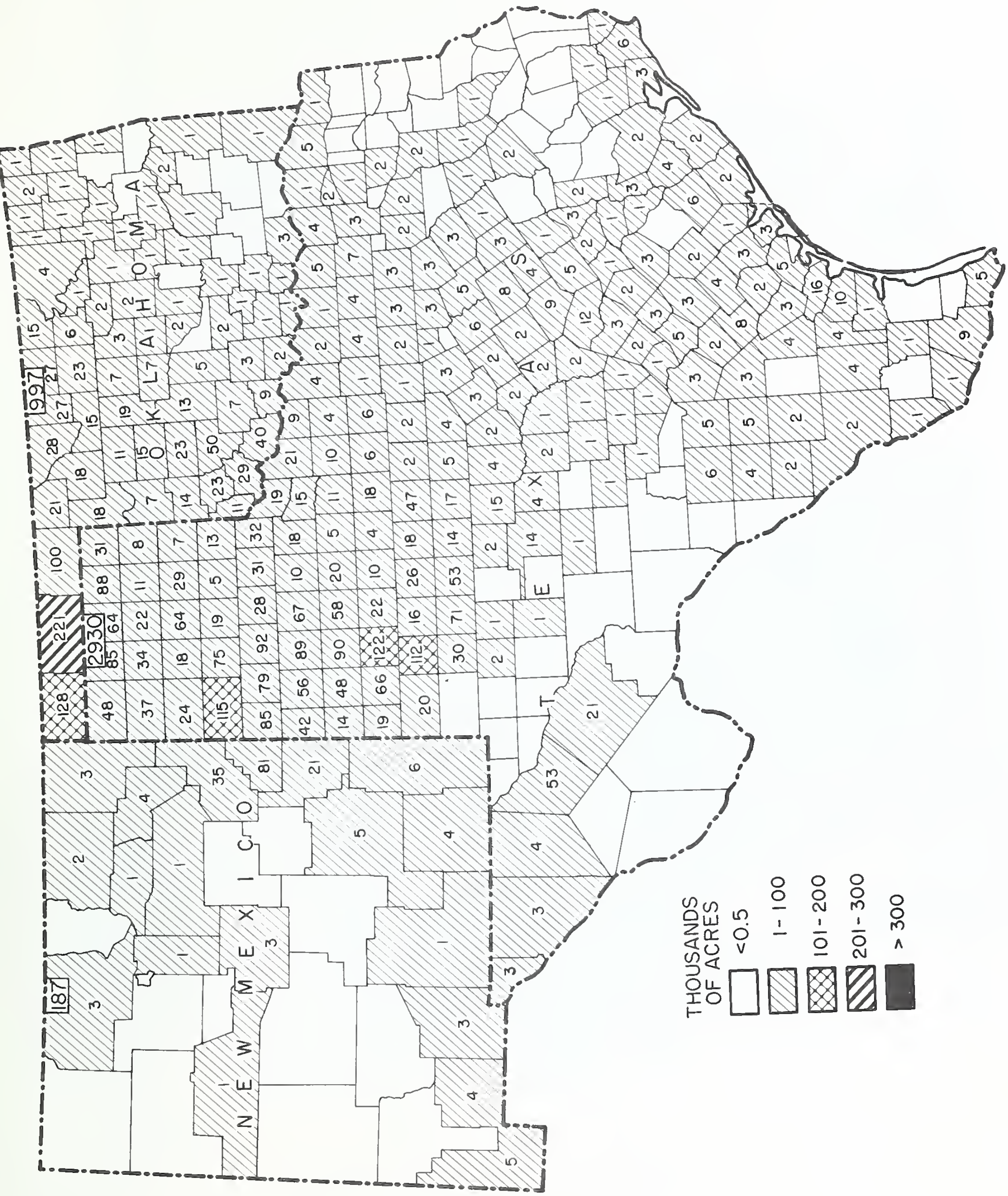

FIGURE 1.2.3.—Thousands of acres of summer fallow in each county of the southern Great Plains (counties with 500 acres or less of fallow are blank) (*9*).

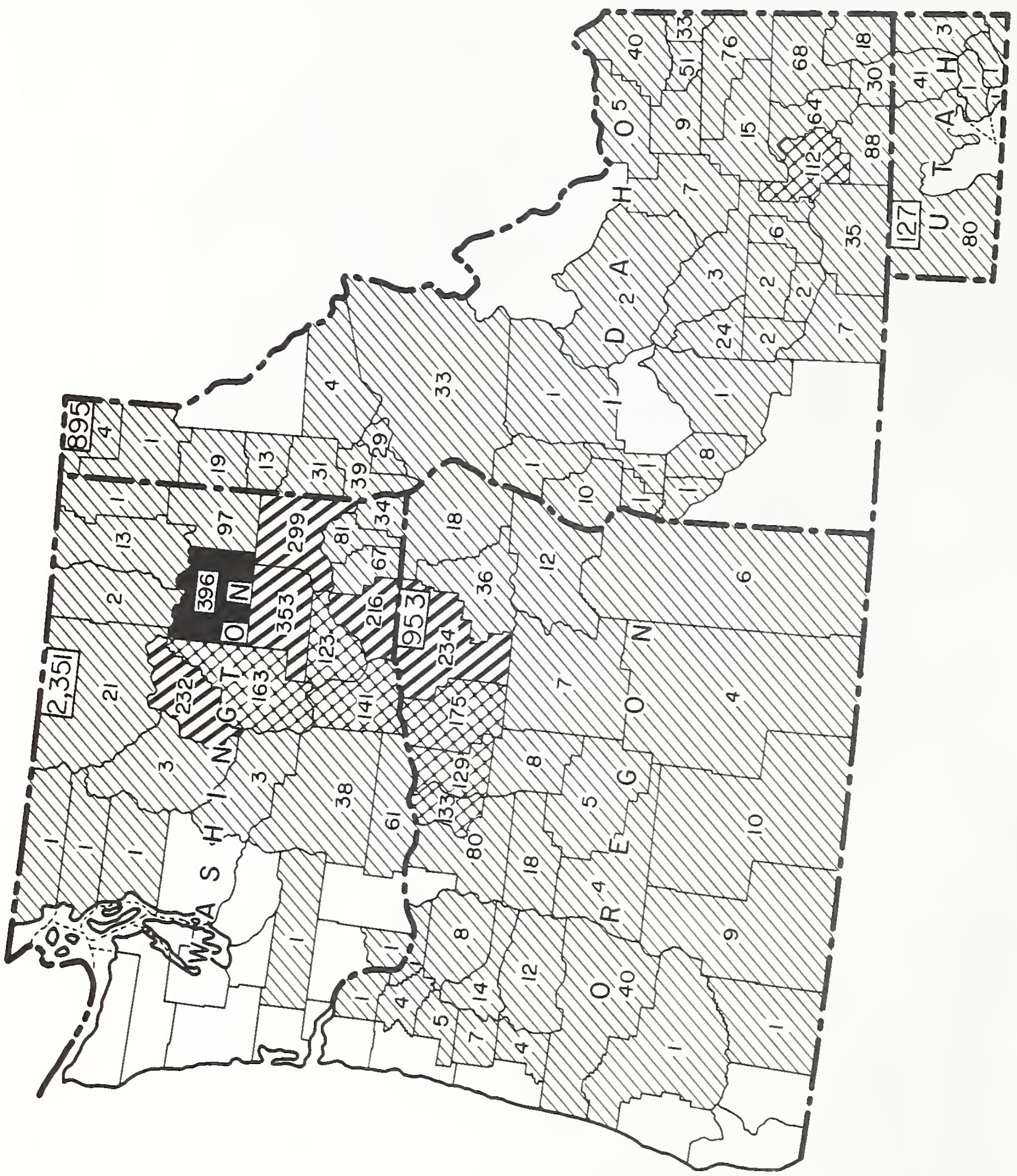

FIGURE 1.2.4.—Thousands of acres of summer fallow in each county of the Northwest (counties with 500 acres or less of fallow are blank) (9).

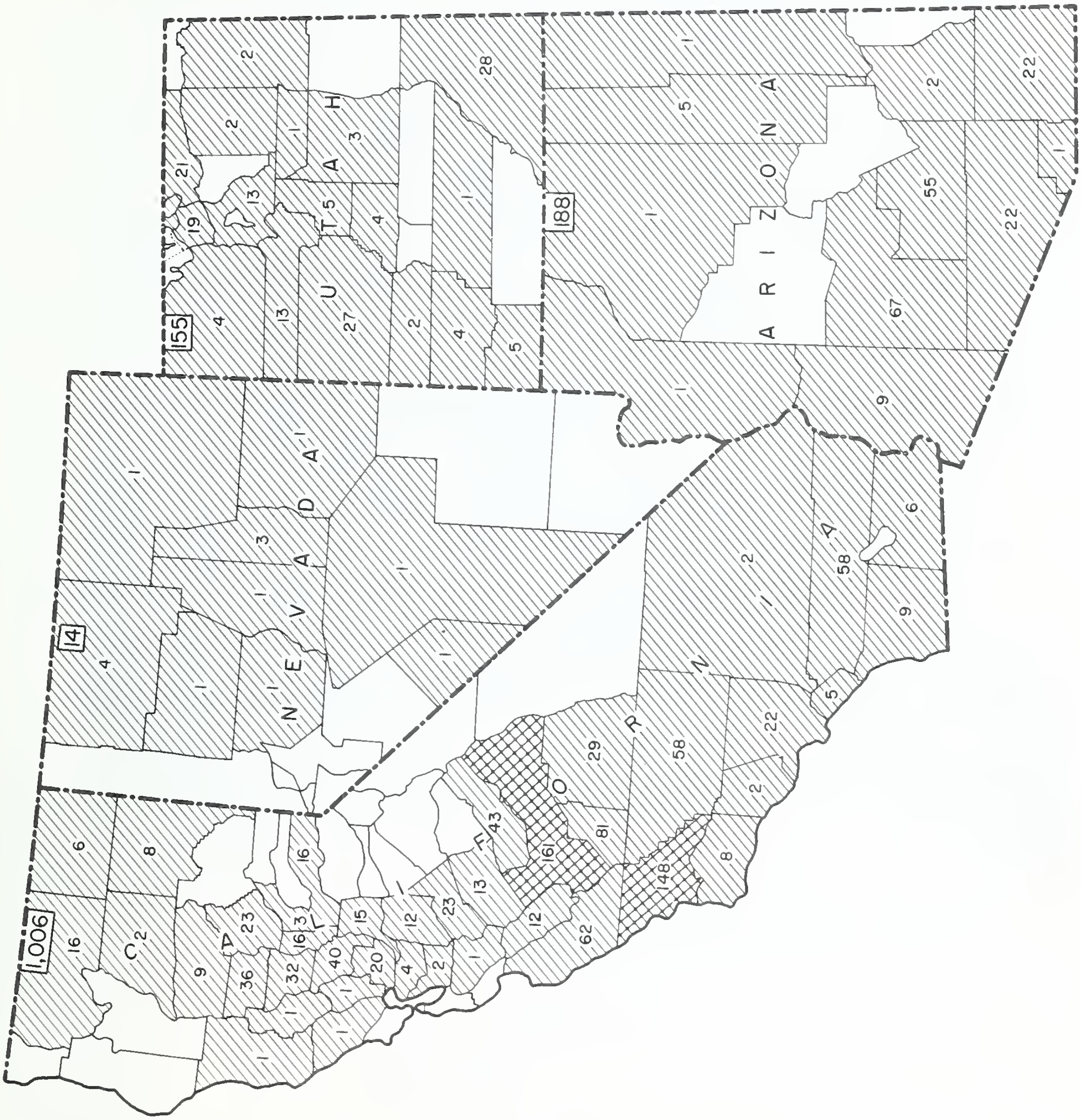

FIGURE 1.2.5.—Thousands of acres of summer fallow in each county of the Southwest (counties with 500 acres or less of fallow are blank) (*9*).

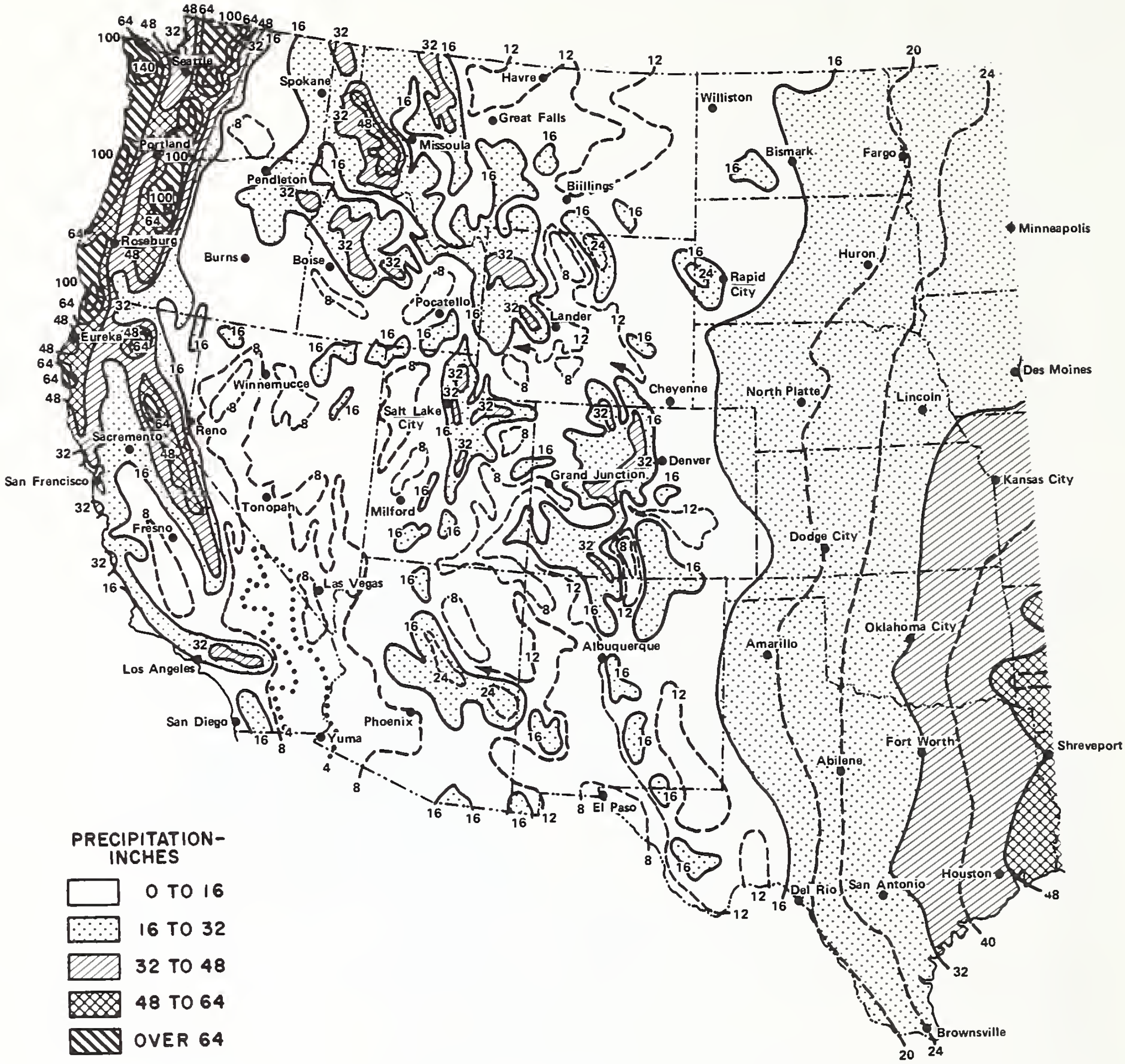

FIGURE 1.3.—Mean annual precipitation, in inches, in the 17 Western States, 1931–60 (*11*).

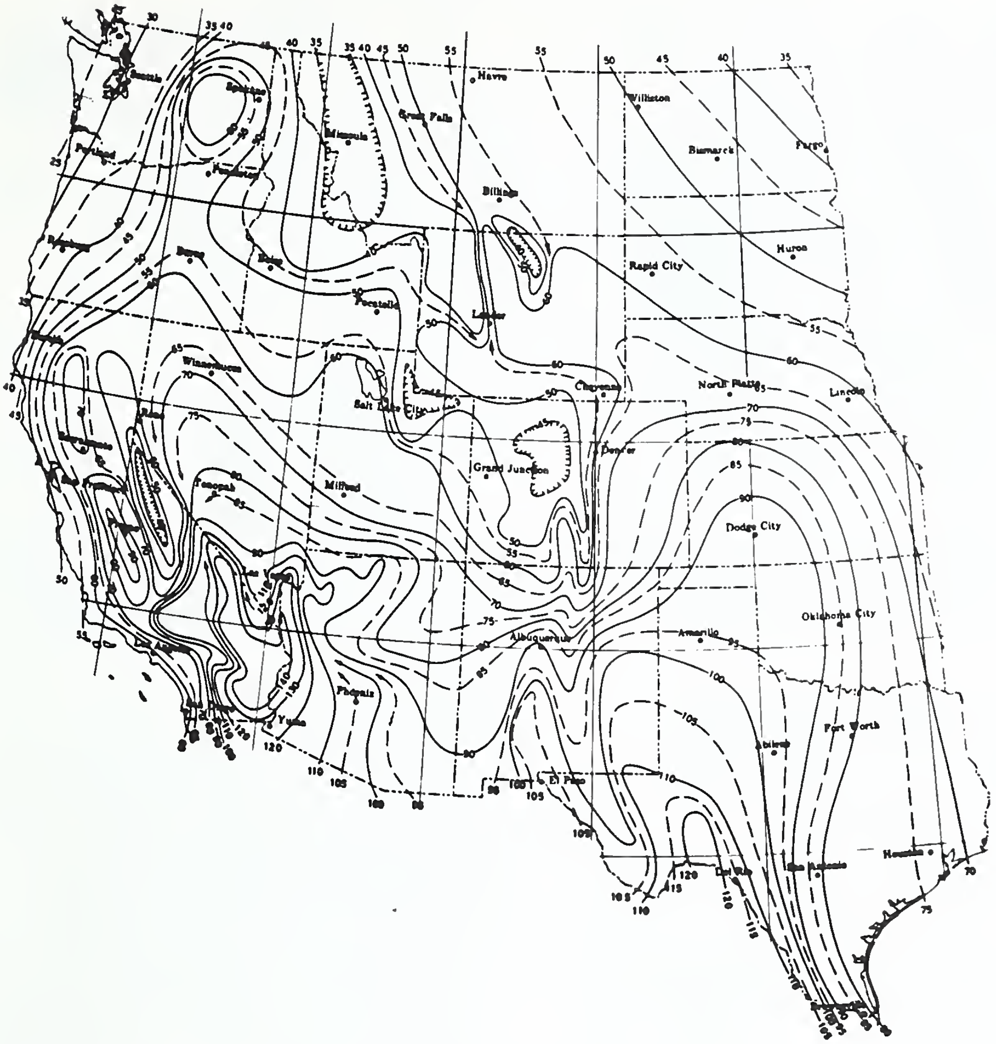

FIGURE 1.4.—Mean annual class A pan evaporation, in inches, in the 17 Western States 1946–55 (*11*).

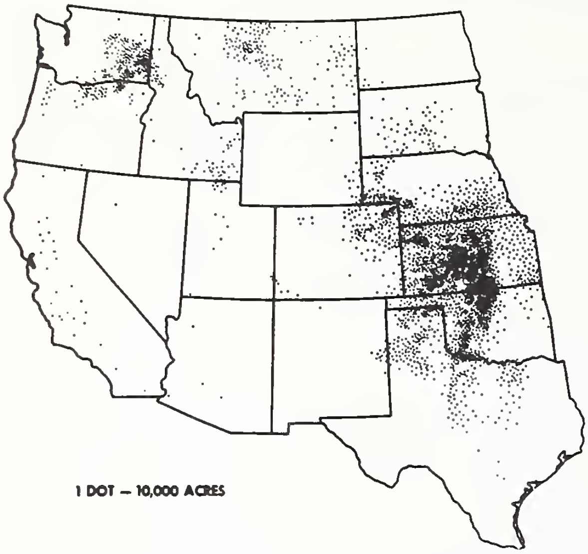

FIGURE 1.5.—Acreage distribution of harvested winter wheat in the 17 Western States in 1964 (*9*).

FIGURE 1.6.—Acreage distribution of harvested spring wheat in the 17 Western States in 1964 (*9*).

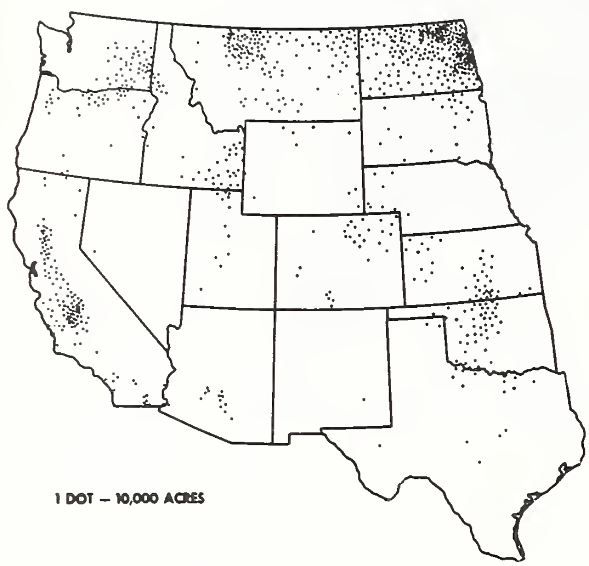

FIGURE 1.7.—Acreage distribution of harvested barley in the 17 Western States in 1964 (*9*).

FIGURE 1.8.—Regions of the 17 Western States arbitrarily defined.

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CHAPTER 2.—SUMMER FALLOW IN THE NORTHERN GREAT PLAINS (SPRING WHEAT)

H. J. Haas, W. O. Willis, and J. J. Bond[1]

Introduction

The Northern Great Plains includes North and South Dakota, Montana, and the northern half of Wyoming (see fig. 1.8). The western parts of Montana and Wyoming are mountainous and the western edge of the Great Plains is generally considered to end at the 5,000-foot elevation. Topography of most cultivated areas of the northern Great Plains is nearly level to rolling.

Climate

Precipitation varies considerably from year to year at any given location, and average annual precipitation ranges from slightly more than 20 inches along the eastern border to about 10 inches along the western plains border (see fig. 1.3). About two-thirds of the annual precipitation falls during April through August, and the higher rainfall months (May, June, and July) nearly coincide with the high water consumption period for small grains. Snow accounts for about 20 percent of the total annual precipitation. Crops usually suffer at least once during their growth from lack of water, and generally use more water than is received as precipitation during the growing period. Thus, in addition to the precipitation received, crop growth is dependent on stored soil water. Because of the comparatively low evaporation (see fig. 1.4), crops make more efficient use of the water received than in regions farther south. Average mean temperature from April through September is about 60° F., and mean annual temperature is about 41°. Temperatures over 100° are not uncommon and lows of more than 50° below zero have been recorded.

Soils

The primary land resource regions (*7*) discussed in this section are the Northern Great Plains Spring Wheat Region (F) and the Western Great Plains Range and Irrigated Region (G) shown in figure 2.1. A small part of the Central Feed Grains and Livestock Region (M) lies along the eastern edge of South Dakota. Soils of the various land resource regions and areas (*7*) have been classified according to the comprehensive system (*99*) as well as by the former system used for Montana and Wyoming (*104*) and for North and South Dakota (*108*).

Udic Borolls (formerly Chernozem soils) occur in eastern North and South Dakota, primarily on the Black Glaciated Plains (area 55). Typic Borolls (formerly Chestnut and Brown soils) are located primarily in resource areas 53 and 54 in western North Dakota and northern South Dakota and along the eastern edge of land resource region E in western Montana. Soils of much of the Northern Rolling High Plains (area 58) and all the Brown Glaciated Plains (area 52) are Aridic Borolls (formerly Chestnut, Brown, Regosol, and Lithosol soils). Udic Ustolls (formerly Chernozem soils) occur in the extreme southeast corner of South Dakota, which is located in the Central Feed Grains and Livestock Region. In south-central South Dakota, which includes the southern part of areas 53 and 55, all of 63, and the northern part of 66, Typic Ustolls (formerly Chernozem, Chestnut, and Brown soils) occur. Aridic Ustolls (formerly Chestnut, Brown, Regosol, and Lithosol soils), occur in western South Dakota and extreme northeastern Wyoming (areas 60, 61, and 64). In south-central Montana and northeastern Wyoming (area 58) Ustollic Aridisols (formerly Regosol, Lithosol, and Brown soils) occur.

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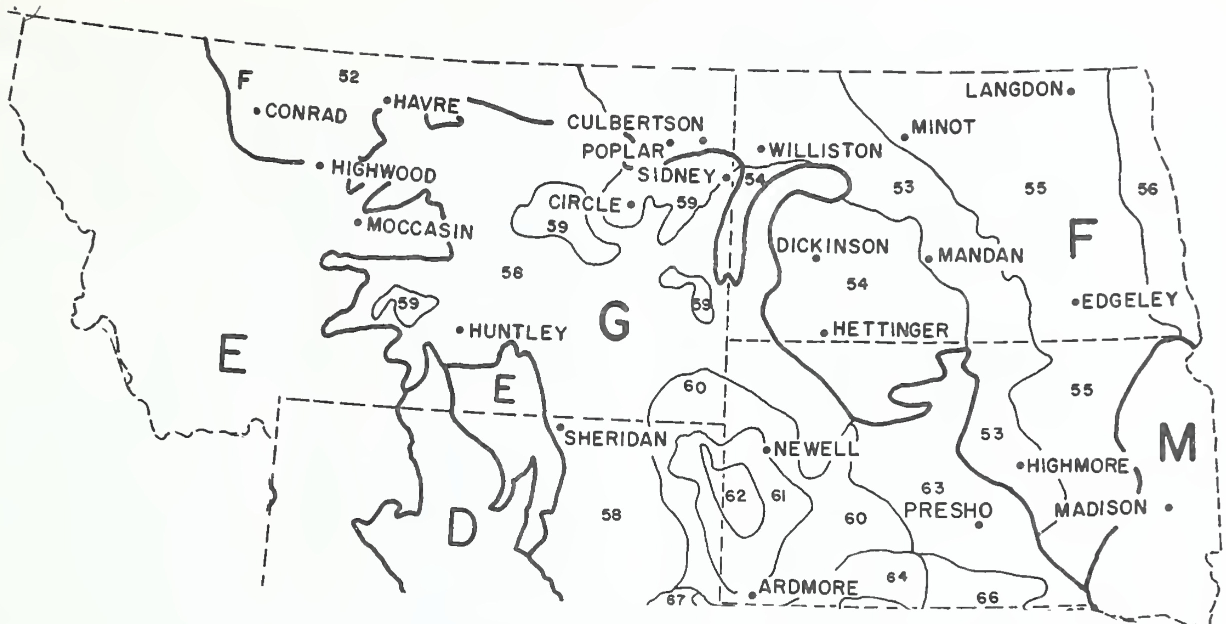

LAND RESOURCE REGIONS AND MAJOR LAND RESOURCE AREAS

D. Western Range and Irrigated Region.
E. Rocky Mountain Range and Forest Region.
F. Northern Great Plains Spring Wheat Region.

52. Brown Glaciated Plains.
53. Dark Brown Glaciated Plain.
54. Rolling Soft Shale Plain.
55. Black Glaciated Plains.
56. Red River Valley of the North.

G. Western Great Plains Range and Irrigated Region.

58. Northern Rolling High Plains.
59. Northern Smooth High Plains.
60. Pierre Shale Plains and Badlands.
61. Black Hills Footslopes.
62. Black Hills.
63. Rolling Pierre Shale Plains.
64. Mixed Sandy and Silty Tableland.
65. Nebraska Sand Hills.
66. Dakota-Nebraska Eroded Tableland.
67. Central High Plains.

M. Central Feed Grains and Livestock Region.

FIGURE 2.1.—Land resource regions and major land resource areas (and locations referred to in text) in the northern Great Plains (7).

Crops and Cropping Practices

The principal crops are small grains, such as hard red winter wheat, hard red spring wheat, durum wheat, barley, oats, and flax. Row crops such as corn and sorghum are of lesser importance. Acreage distributions of winter wheat, spring wheat, and spring barley are presented in figures 1.5, 1.6, and 1.7, respectively. There were more than 14 million acres of summer fallow in the northern Great Plains in 1964 (*97*) (see fig. 1.2). Over 10 million of the fallow acres were planted to all classes of wheat, of which about 55 percent were planted to hard red spring wheat (*100*). In this report the term "spring wheat" will hereafter denote hard red spring wheat. Spring wheat in the northern Great Plains is confined primarily to land resource region F (fig. 2.1). In the higher rainfall areas of the eastern part of the northern Great Plains, alfalfa, potatoes, and sugarbeets are also produced; but as the precipitation decreases westward the acreage and variety of annual crops likewise decreases and the acreage of perennial grass increases.

Over much of the region, selection of different types of crops to include in a rotation is limited. However, corn, where adapted, performs very well in a rotation with spring small grains, and corn land also acts as a partial substitute for fallow for spring small grain production (*31*, *65*, *84*). Where winter wheat can be grown, a rotation of fallow-winter wheat-spring small grains is satisfactory, and affords flexibility in crop selection.

Spring wheat following sorghums in South Dakota has produced less than wheat following fallow, but the sorghum production more than compensates for the loss in wheat yield (*54*, *105*). In the drier areas of the northern Great Plains, the yields of crops that immediately follow legumes or grasses in a rotation are usually depressed because of water deficiency (*5*, *18*, *35*, *83*). Even where legumes are plowed early and the land fallowed until the following spring, yields are frequently no greater than with ordinary fallow. In the higher rainfall areas along the eastern border, legumes increase yields of corn and small grains that follow in years with above-average precipitation, but depress yields in years with below-average precipitation (*18*). Sugarbeets are produced without irrigation in the Red River Valley, and the recommended preceding land treatments are either ordinary summer fallow or green-manure summer fallow.

The frequency of fallow for small-grain production depends to some extent on the amount of precipitation. Alternate wheat and fallow is usually practiced in the drier areas of the western Dakotas and eastern Montana and Wyoming. In areas with higher precipitation, the land may be fallowed only once in 3 or 4 years (*74*). A typical time sequence of field operations and conditions for alternate spring wheat and fallow is:

Time	*Field operations and conditions*
Late July to early August	Harvest wheat
August to mid-May	Undisturbed wheat stubble (first overwinter period)
Mid-May	Initial tillage of fallow
Mid-May to late April	Cultivate summer fallow (includes second over-winter period)
Late April	Plant wheat
Late April through July	Wheat growth
Late July to early August	Harvest wheat

Water Conservation

Storage Efficiency

Soil-water storage during continuous and alternate wheat and fallow cropping systems has been studied by numerous investigators in the northern Great Plains (*1*, *8*, *14*, *15*, *38*, *49*, *67*, *92*, *93*, *95*). Mathews and Army (*67*) summarized results for spring wheat from several locations in the northern Great Plains (table 2.1). From 24 to 40 percent of the precipitation received from harvest to seeding time in an annual cropping system was stored in the soil, while only 14 to 25 percent of the precipitation received during the 21-month fallow period was stored. The mean water storage for the nine locations was 2.5 inches, or 32 percent, under annual cropping and 4.2 inches, or 19 percent, under fallow.

The mean difference in water storage between annual cropping and alternate crop and fallow was about 1.7 inches. Thus, if a method of water conservation could be devised that would store 54 percent of the precipitation from harvest to seeding time in an annual cropping system instead of the present 32 percent, then as much water would be stored as during an entire fallow period.

Investigators have found that about 50 percent (*92*, *95*) to as much as 76 percent (*14*) of the water

TABLE 2.1—*Soil-water storage and storage efficiency during the noncropped period of 2 cropping systems for spring wheat in the northern Great Plains (67)*

Station	Annual cropping				Alternate crop and fallow			
	Years	Precipitation harvest to seeding	Water stored	Storage efficiency [1]	Years	Precipitation harvest to seeding	Water stored	Storage efficiency [1]
		Inches	*Inches*	*Percent*		*Inches*	*Inches*	*Percent*
Havre, Mont	31	6.25	1.84	30	30	17.89	3.51	24
Williston, N. Dak	6	7.75	2.67	34	6	22.43	4.35	19
Huntley, Mont	33	8.31	2.52	30	32	21.51	3.82	18
Dickinson, N. Dak	22	7.76	2.25	29	20	24.34	4.52	19
Mandan, N. Dak. (Main)	40	6.99	2.44	35	39	22.91	3.89	17
Mandan, N. Dak. (South)	20	7.19	1.72	24	19	21.82	3.03	14
Sheridan, Wyo	19	9.83	3.88	40	19	25.09	6.17	25
Newell, S. Dak	47	8.43	2.36	28	45	24.35	4.24	17
Ardmore, S. Dak	13	8.29	3.14	37	11	24.22	4.46	18
Mean		7.87	2.54	32	--------	22.73	4.22	19

[1] Storage efficiency $= \frac{\text{Total inches water stored for all years}}{\text{Total precipitation for all years}} \times 100$

stored during the entire fallow period was stored from harvest to spring of the first year of fallow, and 84 percent was stored by July (*49*). Only small gains, and in some instances losses, occurred during the second winter.

The mean loss of 18.5 inches of water (22.7 inches minus 4.2 inches, table 2.1) during the fallow period is several inches more than the average precipitation received during an entire year at any one of the locations. It seems paradoxical that water should be proclaimed the primary factor limiting crop production in the northern Great Plains, when more than 1 year's precipitation is lost during the fallow period for spring wheat.

Water is lost by evaporation, weed growth, snow removal by wind, runoff, and in some instances by deep percolation. Of these, evaporation accounts for the greatest loss and is the most difficult to control (*67*, *81*). If an economical method of reducing evaporation losses could be perfected, water deficiencies and the need for fallow could be greatly reduced. Weeds can be controlled during the noncropping, or water-storage, period by cultivation and chemicals. Snow is a source of water that is not being fully utilized at present; but tree, annual crop, and grass barriers, standing small-grain stubble, and level benches with nonharvested grass on the dikes are all effective for snow collection (*13*, *16*, *44*, *50*, *51*, *63*, *87*, *107*). Runoff losses can be reduced by maintaining residues on the surface (*112*) and nearly eliminated with level benches (*107*). Deep percolation generally has not been considered a problem in the past. However, during the past 10 to 12 years deep percolation has caused saline seeps to develop in southwestern North Dakota and in the northeast and north-central areas of Montana (*28*, *33*). The seeps occur where soil water, exceeding storage capacity and crop use, moves below the root zone, and where a permeable layer is underlain by a less permeable layer. In southwestern North Dakota, for example, a highly permeable layer of lignite overlays a less permeable layer of shale, and water moves freely in the lignite vein. As surplus water moves downward through the soil and horizontally through the lignite layer, the water together with its dissolved salts, eventually reaches the soil surface and forms a so-called "saline seep." The seeps are associated with the crop-fallow system and are most prevalent in periods with above-average precipitation.

Greater research effort should be made to not only develop better and more efficient water conservation methods but also to devise cropping systems that utilize the water efficiently. There is little to gain, and perhaps much to lose, if more water is stored than is required for crop production.

Methods of Tillage

Numerous investigators have reported very little difference in the effect of various tillage implements (including stubble-mulching types) on water storage during the fallow period if weeds were controlled (*1*, *15*, *32*, *37*, *58*, *64*, *78*, *112*). Black (*12*), on the other hand, reported increases in soil-water storage in fallow at spring wheat seeding time at Sidney, Mont., with increasing quantities of straw on the surface (0, 1,500, 3,000, 6,000 lb./acre). Spring wheat straw production, however, averages only about 2,000 pounds per acre (*1*, *2*, *112*), and it is difficult to maintain sufficient quantities of straw to materially increase water storage during the summer and the second winter of the fallow period.

Timeliness of operation is more important than the type of implement. Results from Swift Current, Saskatchewan (*20*) showed that if all weeds were controlled, 5.1 inches of water was stored in the soil during the fallow period. When initial cultivation began May 15, June 15, and July 15, then 4.5, 3.6, and 1.9 inches of water, respectively, were stored during the fallow period. Delaying initial tillage in the spring resulted in greater weed growth, which reduced soil-water reserves. Thysell (*95*) found at Mandan, N. Dak., that fallow plowed on July 1 contained 1 inch less water at seeding time than fallow plowed on June 1. Black and Power (*15*) reported that fallow receiving June tillage regardless of other times of either tillage or herbicidal applications, or both, was significantly superior in water conservation to fallow without June tillage. Although fields are sometimes cultivated in the fall after wheat harvest, there is little research data indicating greater water storage by this practice (*1*, *15*, *58*, *78*). Fall tillage may possibly be beneficial in years with relatively high precipitation and excessive weed growth. However, disturbing the stubble in the fall even with stubble-mulching equipment may reduce its effectiveness in collecting snow overwinter.

Molberg and others (*71*) found that three or four tillage operations were adequate in experiments at seven locations in Western Canada. Additional operations did not increase stored water. They indicated that the number of operations required for good weed control is adequate for maximum water conservation. When herbicides (2,4-D, Amitrole, Dalapon, or TCA) were used in place of tillage, weed control was not so effective and less water was generally stored in the soil. Similar results were obtained by Black and Power (*15*) with 2,4-D, Dalapon, 2,3,6-TBA, and TCA at Sidney, Mont. However, Molberg and Hay (*70*) in a later study with Paraquat at Regina, Saskatchewan, obtained good weed control and soil-water storage was equal to that from cultivated fallow.

Erosion

Erosion, by both wind and water, is an extremely serious problem throughout much of the Great Plains. Erosion results in direct loss of soil from the field, with deposition occurring in road ditches, fence rows, windbreaks, reservoirs, streams, and around farm and city buildings. Crops are often severely damaged or destroyed. Duststorms can hold up traffic and cause accidents, and the air becomes so polluted that breathing is difficult for both man and animals.

Wind

The extent of wind erosion has been great in the four northern Great Plains States (Montana, Wyoming, North Dakota, and South Dakota); from 1964 to 1970 about $\frac{1}{3}$ to $1\frac{1}{2}$ million acres were damaged annually (*98*). Chepil and others (*26*) stated that "depletion of vegetative cover on the land is the basic cause of soil erosion by wind and water." They also stated that "soil erosion is caused by a strong wind blowing in the direction that gives the greatest distance across a large and unprotected field with a smooth and bare surface and a loose, dry, and finely granulated soil."

Chepil and others (*23*) found that during dry periods wind erosion and duststorms became more serious with time, as vegetative cover and soil aggregation of cultivated land became progressively poorer with each successive dry year. They were able to predict with considerable certainty the severity of wind erosion during a succeeding year from climatic data of the preceding 3-year period. Duststorms are most numerous and severe in the spring. About 80 percent of the storms occur from January through May and tend to be seasonally earlier in the south than in the north.

The quantity of vegetation and the condition of the soil are determined largely by man and climate. Man can manipulate the vegetative cover and till the soil to provide protection from wind erosion if adequate residue is produced. However, during prolonged periods of drought when little vegetation is produced, the problem becomes much more severe. Even with adequate production of vegetative material and when every attempt is made to maintain the residue on the surface (such as by stubble mulching), there is usually not sufficient spring small-grain residue remaining to prevent wind erosion over the second winter and spring of the summer-fallow period. The problem is usually less severe with winter wheat than with spring small grains; if good stands and growth of winter wheat are obtained, there is sufficient plant material to prevent wind erosion over winter and the following spring.

Most of the wind erosion occurs on summer fallow. In addition, fine-textured soils that are moldboard plowed in the fall because they may be too wet to plow in the spring are susceptible to wind erosion (*55*). Also, corn stubble land, where the crop has been harvested for forage or silage, frequently presents a blowing problem. Numerous publications describe methods of reducing wind erosion on fallow. No attempt will be made to refer to all these, but the results and recommendations of a few (*1*, *2*, *3*, *15*, *26*, *32*, *55*, *58*, *66*, *78*, *82*, *85*, *86*, *87*, *91*, *112*) will be briefly summarized.

Stubble-mulch tillage is effective for reducing wind erosion if adequate surface cover can be maintained. As mentioned earlier, the problem in a rotation of spring small grains and fallow is to maintain sufficient residues over the second winter of fallow to control erosion. The quantity of residue necessary is dependent on several factors, including uprightness of residue, soil texture, soil aggregation and roughness, size of field, presence of windbreaks, soil-water conditions, and wind velocities. For example, Chepil and others (*26*) found that when 25 percent nonerodible soil fractions were present, silt loams required 750 pounds per acre of 12-inch standing stubble and loamy sands required 1,750 pounds to reduce soil loss to an insignificant quantity. If the stubble were flattened, twice the quantity of 12-inch stubble was required.

Each tillage operation reduces the quantity of residue remaining on the surface. Anderson and others (*3*) reported results from several experimental stations in western Canada that showed a 10 percent reduction in surface residue from each operation with subsurface cultivators, such as wide blade sweeps or rodweeders; from 15 to 50 percent reduction with mixing implements, such as heavy-duty cultivators or one-way disks; and 100 percent reduction with moldboard plows. Similar results were reported by Krall and others (*58*) for Montana. Four tillage operations were usually sufficient to control weeds during summer fallow (*58*, *71*).

Stubble-mulch tillage not only maintained more residue on the soil surface but also increased both the quantity of nonerodible soil aggregates (>0.84 mm. in diameter) and the amount of surface roughness when compared with moldboard plowing (*58*, *78*); these three factors greatly reduced wind erodibility (*24*).

Strip cropping consists of alternate strips of erosion-resistant crops, such as small grains, and erosion-susceptible land, such as fallow. To be most effective, the strips should be at right angles to the prevailing winds. Strip width depends upon soil texture and may range from 20 feet wide on sand to 430 feet wide on silty clay loam (*26*). Sandy soils are usually a wind-erosion hazard. Siddoway (*87*) reported that alternate strips of wheat and fallow as narrow as 50 feet in Montana failed quite regularly on sandy soils even with stubble mulching. Soil was blown from the fallow strip and was deposited in the stubble strips, forming an undulating terrain. Although strip cropping is effective in reducing wind erosion in many instances, stubble-mulch tillage and other soil-conservation practices should still be used on the erosion-susceptible strips.

Wind barriers are effective for reducing wind erosion when oriented at right angles to the wind, but their effectiveness decreases as wind direction deviation to the barrier increases (*87*). Siddoway (*87*) also reports that barriers, such as multiple- or single-row plantings of trees and shrubs, grass, or artificial windbreaks, are the only means of providing permanent protection concurrent with cultivation of the land. Such barriers have effectively reduced the velocity of winds, blowing perpendicular to the barrier, for a leeward distance of 8 to 12 times the height of the barrier (*25*, *44*). Black and Siddoway (*16*), at Sidney, Mont., reported that two-row barriers of tall wheatgrass spaced 30 and 60 feet apart were effective in reducing wind speeds.

Plantings of single-row tree windbreaks—generally 20 to 40 rods apart, depending on soil type—have increased considerably in recent years. For example, North Dakota, which leads the Nation in miles of tree windbreaks, planted about 9,000 miles from 1939 to 1959, but about 31,000 miles from 1960 to 1971 (information furnished by USDA Soil Conservation Service of North Dakota).

The permeability of the windbreak influences the wind-reduction pattern within the protected area. With a permeable barrier there is less wind turbulence and windspeed reduction is more uniform and extends a greater distance from the barrier than with dense barriers (*44*, *87*). Snow deposition behind a permeable barrier is also more uniform and covers a greater area than behind a more dense barrier (*44*, *45*, *111*), which in turn reduces soil erosion by wind during the winter and early spring. Optimum barrier density for low wind turbulence and for more uniform snow distribution is probably between 20 and 25 percent (*44*, *45*).

During the second winter of fallow, a few rows of annual crops, such as corn, sorghum, sunflowers, and flax, spaced at intervals across the fallow field have been used with varying success. Four rows of flax spaced 12 to 55 feet apart, depending on soil type, are being used in North Dakota for snow collection and for wind-erosion control (*82*, *87*).

Cover crops consisting of spring wheat, barley, oats, or flax seeded in August at low rates (in solid stands or in strips) on summer fallow have been used to reduce wind erosion (*3*, *26*, *106*). When fall growth is sufficient, the cover crops can be grazed, but growth ceases when they are killed by frost early in the winter. The effect of a cover crop on the succeeding crop has varied. In some instances succeeding crops have suffered from water deficiency where the cover crops were grown but in other instances water used by the cover crops has been replenished by extra snow collection in the cover crop. Soil nitrate content may also be low where cover crops were grown. Generally, cover crops have not received widespread acceptance.

Emergency tillage may be required when other measures have failed to control wind erosion. The purpose of tillage is to bring clods to the surface and to leave a roughened condition so the soil will not move. Listers, chisels, or duckfoot cultivators are suitable. Generally, blowing can be stopped by cultivating strips (beginning on the windward side) across the field at right angles to the wind, rather than cultivating the entire field. In the absence of crop residues or cover crops, the field should be cultivated in the fall before freezeup.

Water

Water erosion in the northern Great Plains is generally considered to be most serious on summer fallowed land (*1*, *55*, *58*, *64*, *76*, *85*, *91*). The quantity of data, however, showing actual amounts of soil lost by water erosion in this region is extremely limited. Data from Madison, S. Dak., (*75*) and Morris, Minn., (*96*), both at the extreme eastern edge of the northern Great Plains, show that runoff, and soil and nutrient loss (particularly nitrogen) is much greater from fallow than from other cropping systems (table 2.2). At both locations, the fallow was continuous and bare throughout the periods; thus, the land was more susceptible to erosion than if the fallow had been rotated with crops or stubble mulch tilled, or both.

When crop residues remain on the surface in the stubble-mulch fallow system, soil losses by water erosion are often materially reduced (*61*, *78*, *88*, *112*). For example, at Pullman, Wash., average annual soil losses over a 6-year period with 0, 1, and 2 tons of mulch per acre on the surface were 10.2, 3.6, and 0.8 tons per acre, respectively (*112*).

Crop residues will aid materially in reducing water erosion from torrential rains during the summer of fallow; however, by the second winter only small quantities of residue remain (*55*). Although much of the snow is blown from nearly bare fallow fields the second winter, snowmelt water from adjacent stubble strips or windbreaks may cause serious soil erosion as the water moves across the fallow. Torrential rains that occur soon after the small grains are seeded may cause severe erosion because of the absence of residues. Level benches are effective in controlling runoff and erosion not only from snowmelt but also from torrential rains (*13*, *63*, *107*).

Soil Fertility

Total Nitrogen, Organic Carbon, and Phosphorus

The loss of total nitrogen and organic carbon is generally greater in a rotation containing fallow than under continuous cropping. This fact is not new, but was reported by workers in Minnesota, North Dakota, and Nebraska during the early part of this century (*94*). More recently, other investigators have reported similar findings (*47*, *52*,

TABLE 2.2—*Average annual quantities of runoff and soil loss at Madison, S. Dak., 1962 to 1964, (75) and average annual soil loss and estimated nutrient loss at Morris, Minn., 1961 to 1967 (96)*

Cropping treatment	Madison, S. Dak.		Morris, Minn., loss per acre of—			
	Runoff	Soil loss	Soil	Nitrogen	Phosphorus	Potassium
	Inches	*Tons/A.*	*Tons*	*Pounds*	*Pounds*	*Pounds*
Continuous fallow	3.22	33.49	21.37	183.1	1.07	9.62
Continuous corn	2.47	10.32	9.44	66.4	.85	4.72
Mulch-tilled corn	2.75	9.15	----------	----------	----------	----------
Continuous oats	1.33	1.28	----------	----------	----------	----------
Corn, oats, hay	----------	----------	2.21	31.5	.86	8.42

53, 73, 80). Losses of nitrogen from soil continuously cropped or alternately cropped and fallowed were much less under small grains than under row crops.

Nitrogen can be lost from the soil by crop removal, leaching, volatilization, and by actual removal of the soil material and the nutrients it contains through wind and water erosion. Crop removal would usually not account for the greater loss of nitrogen under fallow than under continuous cropping, because less crop is generally removed from a given area over a period of years under the fallow system than with continuous cropping. Leaching below the depths of sampling could account for some of the differences in nitrogen loss. However, Lehane and others (*59*) found little difference in nitrogen loss in the 4-foot depth between the two treatments. Doughty and others (*34*) presented evidence that in some years nitrogen in fallow is being leached below the depth of root penetration. Power (*77*) also concluded nitrate nitrogen may be leached below the depth of root penetration during a period of fallow as well as under corn. Only rarely will nitrogen move below the root zone of annually cropped small grains and perennial grasses. Volatilization may possibly account for some of the greater loss of nitrogen under fallow. More frequent tillage in the alternate fallow system may increase losses of nitrogen by volatilization (*60*) and denitrification can occur under aerobic conditions (*17*). Doughty and others (*34*) reported that at Swift Current, Saskatchewan, nitrogen was lost from the soil in some gaseous form other than ammonia. Losses by wind and water erosion can be high and are generally greater from fallow than from continuously cropped land as discussed earlier in the section on erosion.

Losses of phosphorus due to cropping have been much less than losses of nitrogen. Phosphorus losses have been about equal for continuous cropping and alternate crop and fallow (*48*). Among the possible causes for lower losses of phosphorus than of nitrogen are: (a) Less phosphorus is absorbed by plants; (b) phosphorus is less mobile than nitrogen and, therefore, is less subject to leaching below the depth of sampling; and (c) phosphorus is not subject to volatilization.

Available Nitrogen and Phosphorus

During the summer-fallow period, temperature and soil-water conditions are usually favorable for the microbial decomposition of organic matter and the release of nitrate nitrogen. Consequently weed-free summer-fallowed soils generally contain more nitrate nitrogen at planting time than continuously cropped soils (*9, 39, 40, 55, 59, 69, 91*). For example, Bauer and others (*9*) reported that fallowed soils contained an average of 82 more pounds of nitrate nitrogen per acre in the surface 4 feet at 63 locations in North Dakota than nonfallowed soils. At seven of the locations, nonfallowed soils contained more nitrogen than fallowed soils. Lehane and others (*59*) reported considerably more nitrate in the upper 57 inches of fallowed than in nonfallowed soils, particularly in the 36- to 48-inch depth. Doughty and others (*34*) found high concentrations of nitrate below the normal depth of root penetration (4 feet) in fallowed Brown soils of Canada.

Numerous investigators have reported that nitrate formation is usually depressed when crop residues are maintained on the surface (*9, 61, 112*). However, Smika and others (*89*) found that high rates of straw were necessary before nitrate was reduced significantly. McCalla and Army (*61*) stated that "Apparently the depressive effects of residues are spread over a longer period of time with stubble mulching than is the case with plowing. In general, if nitrate is measured in the field any time in the spring or early summer, nitrate content is 5 to 7 percent less with stubble mulch than with plow tillage. If soil samples are taken in the fall or winter, nitrate content may be higher under stubble mulching than with plowing."

Ferguson and Gorby (*40*) periodically analyzed the surface 6 inches of summer fallow soil in Manitoba from August 30 of one year to August 27 of the next year where different rates of straw had been applied. There was little difference in nitrate production between 0- and the 1,500-pound straw rate on any sampling date. However, the 3,000- and 4,500-pound rates reduced nitrification on most sampling dates beginning May 6.

From the foregoing, it is evident that greater quantities of nitrate will generally accumulate under fallow than under continuous cropping and that some of this nitrate may be leached below the depth of root extraction by cereal crops. Also, the quantity of nitrate in fallow will usually be lower with than without surface residues.

Available phosphorus of summer-fallowed soil is usually higher than that of continuously cropped soil (*48*, *59*). Results from studies comparing available phosphorus contents of stubble-mulched fallow with plowed fallow soils are variable (*61*, *112*). Zingg and Whitfield (*112*) concluded that "available phosphates tend to be concentrated nearer the surface on stubble-mulched plots than on plowed plots." They suggested that this higher concentration of available phosphorus in the surface of stubble-mulch soil might benefit early seedling growth and root development more than in plowed soils.

Crop Yields

Increases From Fallow

Crop yields, in nearly all instances, are higher after fallow than in an annual cropping system, primarily because of the greater water and nutrient supplies, fewer weeds, and less plant disease. The yield increase from fallow varies considerably from year to year at a given location as well as between locations. Wheat yields after fallow, expressed as a percentage of yields after wheat or corn, at a number of experiment stations in the northern Great Plains are presented in table 2.3. These data show the wide range in effect of fallow between locations. The increase in yields after fallow ranged from 18 percent at Froid, Mont., to 95 percent at Havre, Mont., over yields after wheat; and from 3 percent at Moccasin, Mont., to 32 percent at Froid over yields after corn. For any given location, the variation in effect of fallow is probably due primarily to differences in soil water at seeding time and to available nutrients (mainly nitrate N). Precipitation and temperature during the growing season are also important factors influencing yield (*4*). Although precipitation and temperature are the same at a given location, the interaction of rainfall, temperature, fertility, and soil water could result in dissimilar influences on yield for the two cropping treatments.

Yields on fallow were never 100 or more percent higher than those after wheat. A 100-percent yield increase on fallow every other year is necessary to obtain as much wheat as with annual cropping. However, the advantage of fallow does not need to be 100 percent greater in order to be economical. It is difficult to establish a break-even point, because differences in production costs and market prices will affect net return. However, using data provided in Bauer's report (*8*), it appears that fallow should increase wheat yields more than 50 percent to be considered economical based on a price of $1.50 per bushel of wheat. MacKenzie (*62*) concluded from a study in Saskatchewan that when fallow increased wheat yields more than 54 percent over stubble land, an alternate wheat-fallow rotation would tend to dominate at a farm price of $1.50 to $1.65 per bushel of wheat. When the increase from fallow was 34 percent to 54 percent, then a rotation containing 1 year fallow in 3 or 4 years would be suitable with the 1 year in 3 dominant. With a yield increase from fallow over stubble land of 33 percent or less, then a rotation of 1 year fallow in 4 or more years would be suitable. Austenson and others (*6*) state that "One cost of summer fallowing which cannot be accurately estimated is the soil erosion hazard. Both wind and water erosion are much greater when the land is fallowed and tilled for a complete growing season. This cost should somehow be considered in assessing the need for summer fallowing." Thus not only the economic welfare of the present land owner or operator

TABLE 2.3.—*Average yields of spring wheat on fallowed land compared with yields after wheat or corn, percentage increase after fallow, and corn yields at a number of experiment stations in the northern Great Plains*

State, location, and reference	Yield period	Yield of wheat (bu./acre) from— Fallowed land	Yield of wheat (bu./acre) from— Wheat-stubble land	Yield of wheat (bu./acre) from— Corn-stubble land	Percentage increase in yield from fallow over yield from— Wheat-stubble land	Percentage increase in yield from fallow over yield from— Corn-stubble land	Corn yield per acre Grain, bushels	Corn yield per acre Air-dry fodder, pounds
Montana:								
Havre (*57*)	1917–51	15.6	8.0	11.9	95	31	12.6	2,500
Moccasin (*57*)	1909–51	16.2	11.7	15.6	38	3	----	3,480
Huntley (*57*)	1913–51	14.8	8.5	13.1	74	12	16.8	2,200
Froid (*1*)	1941–47	28.5	24.1	21.5	18	32	24.8	4,090
North Dakota:								
Williston (*72*)	1910–20	18.0	14.1	14.4	28	25	14.1	4,280
Dickinson (*31*)	1908–51	20.9	11.6	19.5	80	7	19.3	3,810
Hettinger (*72*)	1912–22	16.9	11.6	15.4	46	9	----	[1] 6,400
Mandan (*31*)	1915–48	20.9	14.9	16.0	40	30	26.6	3,780
Langdon (*43*)	1941–52	28.1	20.3	----	38	----	----	----
Edgeley (*43*)	1941–53	22.7	17.9	----	27	----	----	----
Minot (*43*)	[2] 1947–56	26.4	18.3	----	44	----	----	----
South Dakota:								
Newell (*76*)	1909–48	21.2	13.6	17.1	55	23	16.1	2,800
Ardmore (*68*)	1913–30	20.7	11.9	17.4	73	18	15.2	3,120
Highmore (*90*)	1942–55	22.2	13.2	18.2	68	22	25.1	----
Wyoming, Sheridan [3] (wheat-*65*)	1918–50	24.7	14.8	20.6	66	19	14.7	2,260

[1] Green weight.
[2] Yields from only 5 years used.
[3] Corn data from annual reports, U.S. Field Station, Sheridan, Wyo.

should be considered in assessing the economic virtues of a cropping system but also the present and future welfare of the public as a whole.

Where wheat followed corn, yields were higher than those where wheat followed wheat at all locations except Froid, Mont. (table 2.3). Percentage increases of yields after fallow over yields after corn were all low; this indicates that corn is a good substitute for fallow. Although the yields of corn were not impressive, in most instances they would more than offset the reduction in wheat yield obtained after corn as compared with those after fallow. With present-day earlier maturing corn varieties, grain yields should be higher than those produced in the past. If corn were included in the rotation, then additional machinery would be required. Also the corn should probably be fed on the farm, which may involve the addition of livestock to the farming operation. As mentioned earlier, when corn is grown for silage, the resulting land surface after harvest may be highly susceptible to wind and water erosion. These factors would need to be considered in determining the desirability of substituting corn for fallow.

Where small grains are grown continuously, weeds often become a problem. The broadleaf weeds can usually be controlled by herbicides, but grassy weeds such as wild oats [*Avena fatua* L.], green foxtail [*Setaria viridis* (L) Beauv.], and yellow foxtail [*Setaria lutescens* (Weigel) F. T. Hubb] become more of a problem. However, in Canada Dryden and Whitehead (*36*) were successful in controlling seed setting of foxtail in wheat with low rates of TCA. Periodic summer fallowing may be necessary to reduce infestation of grassy weeds (*6*). If corn is kept free of weeds during the growing season, weed populations in the succeeding spring small grain crop are materially reduced (*22*, *84*).

Production Stability

Average yields presented in table 2.3 are satisfactory for determining expected yields over a period of years. However, they do not indicate the stability in production from a particular cropping system. One of the advantages of summer fallow often mentioned is that production is more stable than from an annual cropping system. Probabilities of obtaining various yields after fallow or from continuous cropping were determined by plotting yield-probability curves from data from a number of experiment stations by the incomplete gamma function (*41*). The curves (figs. 2.2–2.5) compare spring-plowed fallow with spring-plowed continuous cropping, except at Sidney, Mont. (fig. 2.2B). At Sidney, the fallow was stubble-mulch tilled instead of plowed, and data were not sufficient to compute a curve for annual cropping. The curves show the probability of obtaining a yield equal to or in excess of that indicated. For example, at Mandan, N. Dak. (fig. 2.3B), the probability of obtaining at least a 10-bushel per acre yield from continuous cropping is about 61 percent, but after fallow the probability is about 87 percent. At Havre, Mont. (fig. 2.5A), the percentage values were 30 and 63, respectively.

Thus, the curves can be used not only to determine the yield probability at a given location but also to compare production probabilities between locations. The probability of obtaining higher yields from fallow was greater than from continuous cropping at nearly all yield levels and locations. These curves were derived from long term data developed in the earlier days of the old dryland experiment stations; hence, they do not reflect some of the more recent fertilizer and tillage practices and overall improvements in production technology. For example, by adding nitrogen during annual cropping, the curves would likely be closer together.

Fertilizer Effects

The results presented in table 2.3 were from trials without fertilizer application. When proper fertilizers are applied, the relation between yields from fallow and from annual cropping are usually altered, as indicated by results from North Dakota (69 trials), South Dakota (15 trials on fallow and 20 nonfallow) and Montana (4 trials) (table 2.4). The increase in yield of the fallow check over the wheat-wheat check ranged from 4 to 60 percent. But when fertilizer was applied to the wheat-wheat system, the percentage increase from nonfertilized fallow (check) was reduced considerably, ranging from −24 to 26 percent. Thus, much of the yield advantage of fallow was due to a greater supply of available nutrients (primarily nitrogen) rather than greater water storage (*46*, *69*, *109*). When fertilizer was applied to both wheat on fallow and to the wheat-wheat system, the percentage increase from fallow (last column) was reduced at some locations, compared with nonfertilized treatments, and was

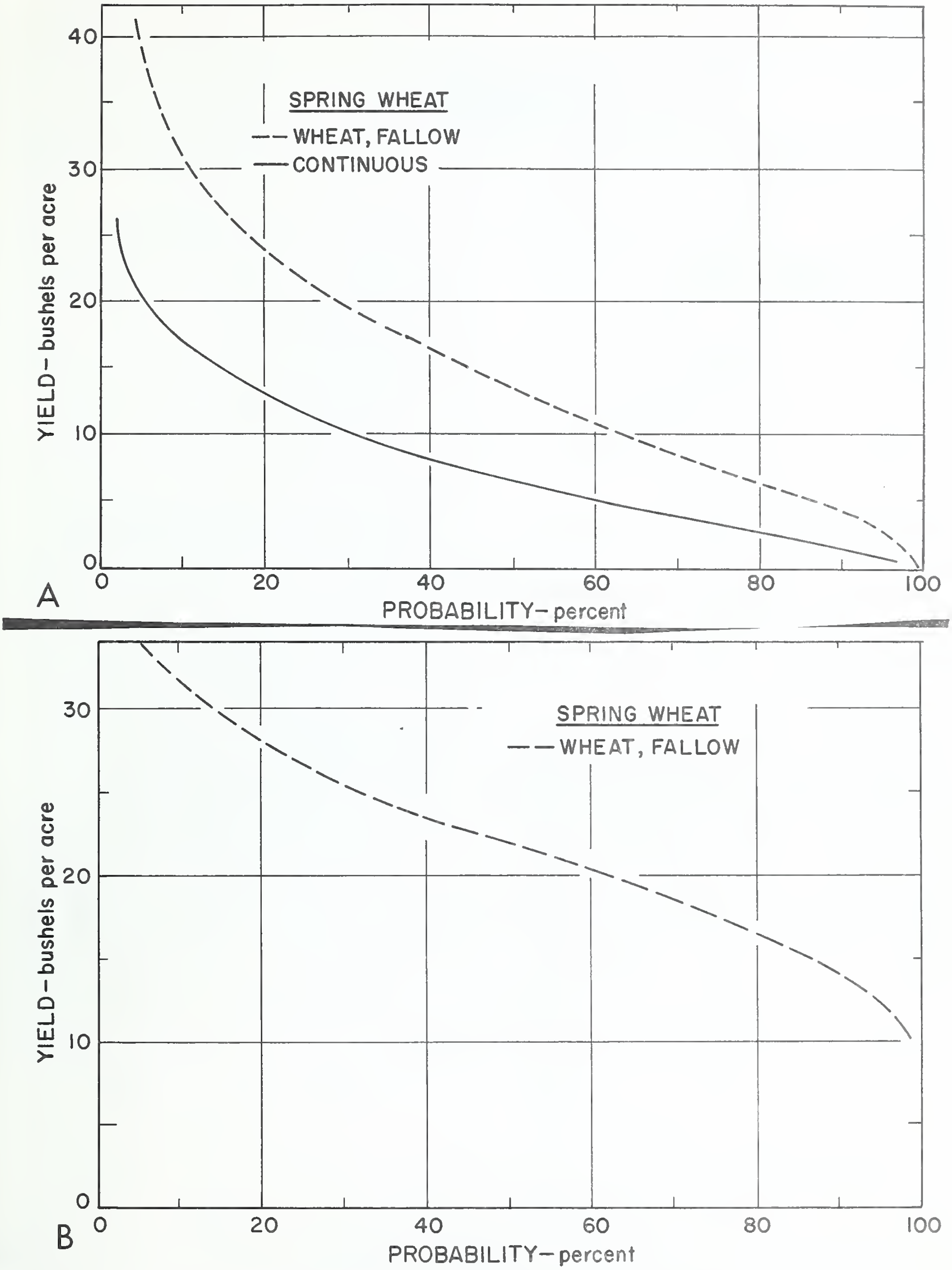

FIGURE 2.2—Curves showing probability of obtaining a specified yield or more of spring wheat: *A*, with two cropping systems at Havre, Mont., 1917–54; *B*, on fallow at Sidney, Mont., 1941–70.

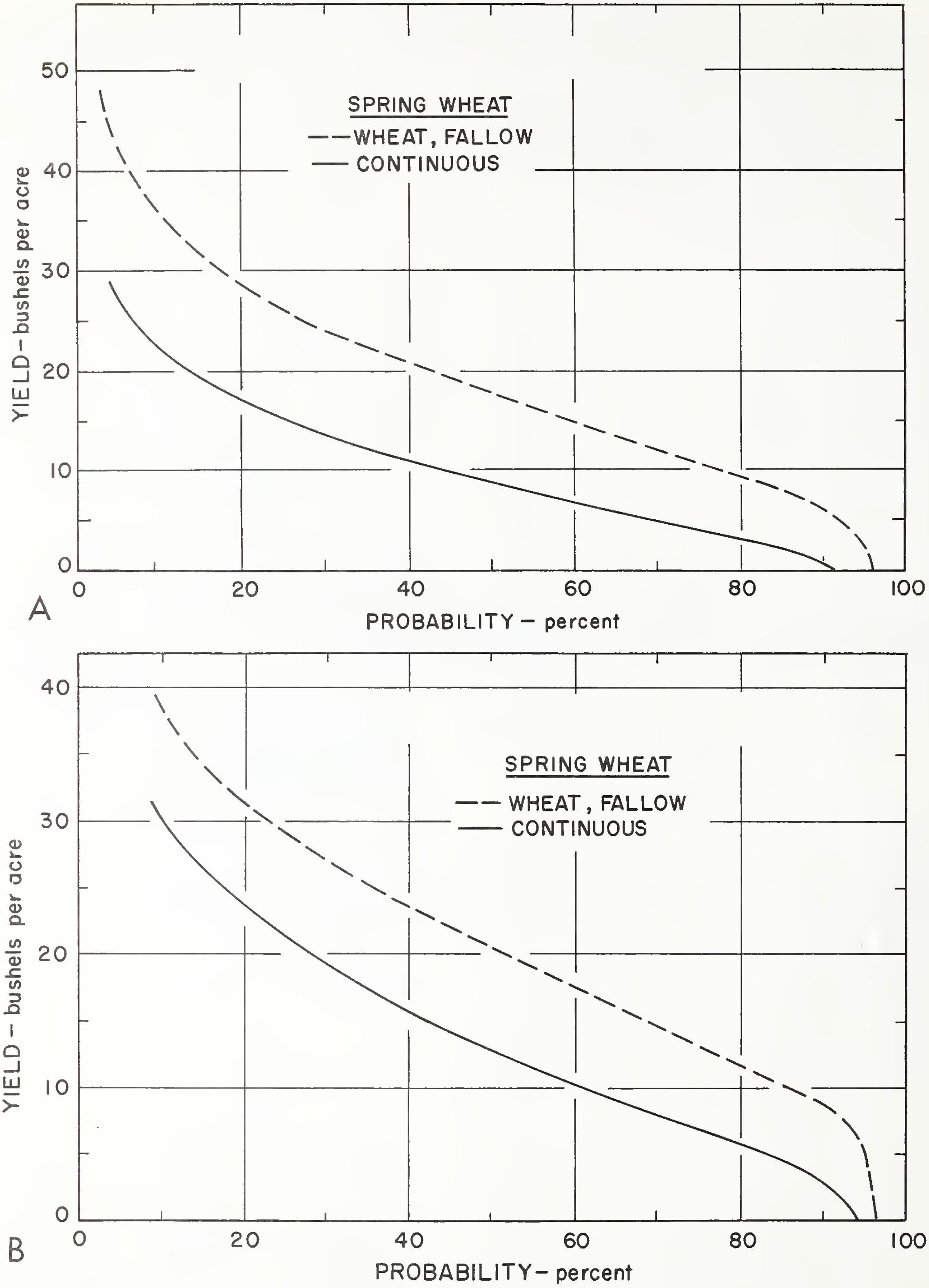

FIGURE 2.3.—Curves showing probability of obtaining a specified yield or more of spring wheat with two cropping systems at: *A*, Dickinson, N. Dak., 1908–52; *B*, Mandan, N. Dak., 1915–54.

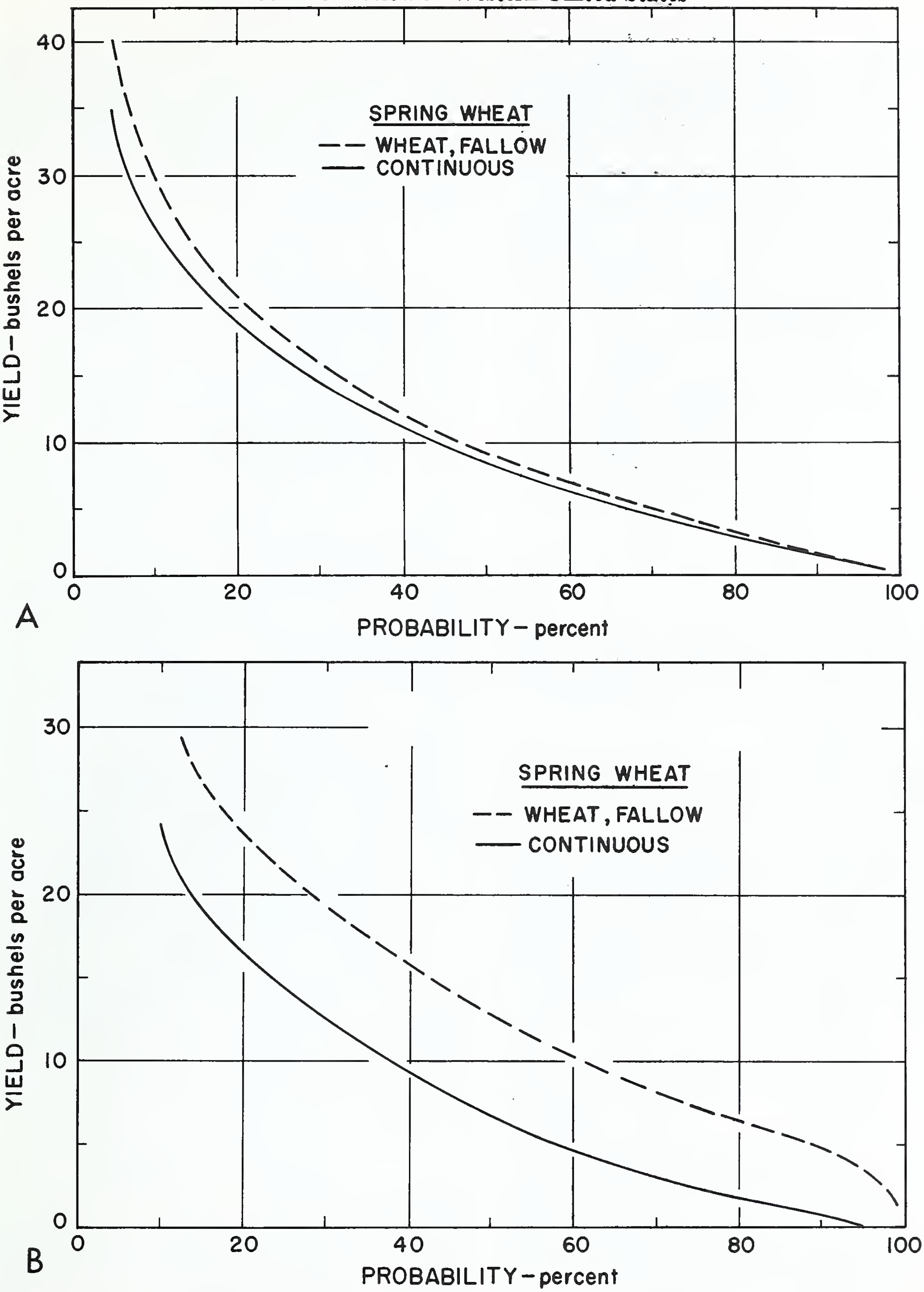

FIGURE 2.4.—Curves showing probability of obtaining a specified yield or more of spring wheat with two cropping systems at: *A*, Edgeley, N. Dak., 1907–21; *B*, Highmore, S. Dak., 1912–30.

increased slightly at others. The results from North Dakota depict very well the increasing benefits derived from fallow as precipitation decreases from the Red River Valley in the east to the western part of the State.

The data from Montana are limited because most of the fertilizer trials in the past have been primarily on summer-fallowed land. In the past decade studies were initiated on annually cropped land that included adequate fertilizer rates. Barley has responded very well to fertilizer at several locations in Montana. At Moccasin (*27*), 11-year average barley yields on fallow were 33 bushels per acre without fertilizer and 40 bushels with 20 pounds of nitrogen and 30 pounds of P_2O_5 per acre annually. Continuous barley yields were 22 bushels without fertilizer and 30 bushels with 20 pounds of nitrogen and 40 pounds of P_2O_5 per acre annually. Table 2.5 shows that barley yields were materially increased by application of high rates of nitrogen at three locations in central and north-central Montana (*27*). The increase from fallow was also considerably reduced by applying nitrogen. Although the results are for only 2 years at Moccasin and Highwood and for only 1 year at Conrad, they do indicate some of the possibilities for annual cropping with adequate fertilization.

By applying fertilizers to annually cropped land, the acreage of summer fallow could be reduced in many areas. The response of crops to fertilizer depends upon the soil-water content at seeding time, growing-season precipitation, and temperature, nutrient status, and nitrification rate of the soil (*10*, *79*, *102*, *110*). Precipitation and temperature are difficult to predict at planting time, but both soil water and nutrient status can be measured.

Bauer and others (*10*), in reporting results from 66 trials on nonfallowed soils in North Dakota, showed that 20 pounds of nitrogen per acre produced the highest wheat yields with less than 2 inches of stored water at seeding, 40 pounds of nitrogen with 2 to 3.99 inches, and 60 pounds of nitrogen with 4 or more inches. Young (*109*) stated that "when soil is moist to a depth of 2 feet or more at seeding time and weeds are under control, there is little or no justification for fallowing in any part of North Dakota." Calculations of results presented by Cole and Mathews (*29*), showed that spring-plowed continuously cropped soil was wet to 2 feet or more at 10 experimental sites in the northern Great Plains from 45 to 85 percent of the years, with an average of 67 percent. At six of the 10 sites, the soil was wet to a depth of 2 or more feet in 67 percent of the years. Thus, from the standpoint of soil-water content at seeding time for continuous wheat, there should be sufficient water for fertilizer response at a number of locations in the northern Great Plains in most years.

Tillage Effects

Numerous studies have been conducted to determine the effect of various types of fallow tillage on crop yields (*1*, *15*, *31*, *32*, *35*, *37*, *42*, *43*, *55*, *57*, *58*, *64*, *76*, *78*, *112*). Generally speaking, type of tillage has influenced wheat yields very little. There has been, however, a tendency for stubble-mulch tillage to produce higher yields than clean tillage in the drier areas (*112*). Smika and others (*89*) reported higher spring wheat yields at Sidney, Mont., with increasing rates of straw mulch applied at the beginning of the fallow period. It is fortunate that stubble-mulch tillage does not reduce yields compared with onewaying or moldboard plowing, because it also aids in reducing wind and water erosion. Stubble-mulch tillage is, therefore, the recommended practice for summer-fallow management.

However, wheat-straw residues on the soil surface can be a source of inoculum of cereal leaf diseases caused by Septoria and Helminthosporium fungi (*56*). Wheat plants near the surface residues may be infected by these fungi. In those areas where leaf diseases are a problem, it may be necessary to begin initial tillage early and to flatten the stubble so that decomposition of straw will be more rapid. For best disease control, no residues should remain on the surface at planting time.

Time of initial tillage usually has more effect on yield than types of tillage. Tillage should be completed at least by June 1 (*30*, *35*). Complete weed control is desirable during the spring period of peak soil-water storage on fallow (*49*). Yields may be reduced an average of 4 bushels per acre by delaying tillage until July 1 (*30*, *35*, *55*, *95*).

Water-Use Efficiency

Water-use efficiency is normally defined as "The weight of dry matter or marketable crop produced per unit volume of water used in evapotranspiration" (*101*). Evapotranspiration includes only that water lost by evaporation from the soil and transpired by the crop during the cropping period. However, in comparing the efficiency of water use

TABLE 2.4.—*Average yields of spring wheat after wheat and after fallow with and without fertilizer, and percentage increases from fallow, in North and South Dakota and Montana*

Location and reference	Number of years	Yield bu./acre: Wheat-wheat Check	Wheat-wheat Fertilized	Wheat-fallow Check	Wheat-fallow Fertilized	Percentage increase in yield: Fallow check over wheat-wheat check	Fallow check over wheat-wheat fertilized	Fallow fertilized over wheat-wheat fertilized
North Dakota (*8*):								
Red River Valley	4	28.0	38.0	29.0	41.0	4	−24	8
East-central	4	22.0	29.0	28.0	38.0	27	−3	31
West-central	4	18.0	22.0	26.0	33.0	44	18	50
West	4	16.0	19.0	24.0	30.0	50	26	58
Montana (*27*): central (Moccasin)	4	13.0	19.5	20.8	23.5	60	7	21
South Dakota (*21*): northern half	3	14.3	18.3	19.7	23.7	38	8	30

TABLE 2.5.—*Yields of spring barley continuously cropped and on fallow with different rates of nitrogen and percentage increases from fallow at three locations in Montana (27)*

Pounds nitrogen applied per acre [1]	Yield, bu./acre [2]: Moccasin Barley-barley	Moccasin Barley-fallow	Highwood Barley-barley	Highwood Barley-fallow	Conrad Barley-barley	Conrad Barley-fallow	Percentage increase in yield: Fallow check over barley-barley fertilized: Moccasin	Highwood	Conrad	Fallow fertilized over barley-barley fertilized: Moccasin	Highwood	Conrad
0	15	35	23	55	13	58	133	139	346	133	139	346
20	28	40	34	60	28	64	25	61	107	43	76	128
40	32	46	45	70	32	64	9	22	81	44	56	100
60	32	45	54	70	35	62	9	1	65	41	30	77
80	32	48	59	70	39	61	9	−7	48	50	19	56
120	31	46	62	68	32	59	12	−12	81	48	10	84

[1] All plots contained 20 pounds per acre available P and 25 pounds available K per acre.
[2] Average yields for 1969 and 1970 at Moccasin and Highwood and 1969 only at Conrad.

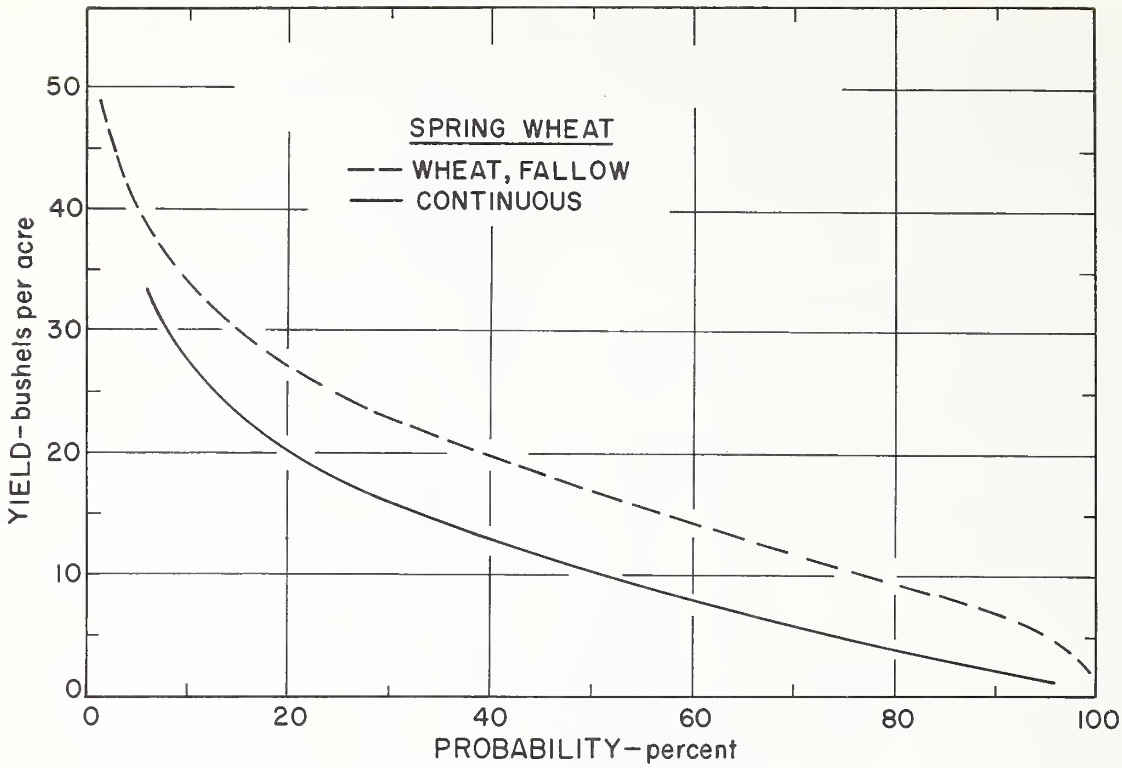

FIGURE 2.5.—Curves showing probability of obtaining a specified yield or more of spring wheat with two cropping systems at Ardmore, S. Dak., 1913–32.

by cropping systems, particularly under dryland conditions, all forms of water use influenced by the cropping system should be included. Thus, in this publication, water use encompasses evaporation from the soil, transpiration from crops and weeds, runoff, snow removal by wind, and, in some instances, deep percolation, not only during the cropping period but during the noncropped period as well.

Because, in the absence of a water table, all water received by dryland crops comes from precipitation, water-use efficiency of annually cropped small grains is calculated by dividing grain production by the amount of annual precipitation. Similarly with alternate crop and fallow, grain production is divided by twice the annual precipitation. Thus, the water-use efficiency value as used here indicates how efficiently the precipitation received from harvest to harvest is used by a cropping system for the production of wheat grain. Low values indicate poor efficiency, and high values indicate good efficiency.

For alternate spring wheat and fallow, the mean water-use efficiency value, was 0.69 bu./in. and ranged from 0.54 to 1.13 bu./in. (table 2.6). For annual cropping, the mean was 0.93 bu./in. and ranged from 0.66 to 1.91 bu./in. At most locations, water-use efficiency was considerably higher for the annually cropped system and probably would have been even higher with proper fertilization.

Crop Quality

Hard red wheats are used for making bread, and a high protein content is desirable. Protein content of spring wheat grain is usually higher when grown on fallow than when annually cropped, and is generally lower from stubble mulch-tilled than from clean-tilled land (*1, 19, 37, 39, 58, 78, 103, 112*). However, with adequate N fertilization, these differences are largely eliminated.

Bell (*11*) reported that fallow produced No. 1 spring wheat (based solely on test weight) less frequently than spring-plowed or spring-disked stubble land over a 15-year period at Havre, Mont. However, the average test weights varied little for the period.

Aasheim (*1*) showed that the second crop of wheat after fallow had a higher test weight than the first crop after fallow, while wheat after corn or idle land had the highest test weight. There was little difference due to various tillage methods. Krall and others (*58*) reported small differences in test weights due to methods of tillage on fallow at Havre, Froid, and Moccasin, Mont., but stubble-mulched fallow produced grain with a slightly higher test weight at all three locations. They attributed the higher test weights to thinner stands obtained on stubble-mulch fallow. Power and others (*78*) found that grain produced on stubble-mulch tilled fallow had a slightly higher test weight than on plowed fallow. They concluded that, based on protein content and test weight of grain, it was not likely that the tillage method used during summer fallow would have any appreciable effect upon the market value of the grain.

Summary and Conclusions

Over 14 million acres were summer fallowed in the northern Great Plains in 1964 (*97*), and the acreage was distributed in nearly every county in the region (see fig. 1.2). Over 10 million of the fallow acres were planted to all types of wheat, of which nearly 5.5 million were planted to hard red spring wheat. About 2.8 million acres of hard red spring wheat were planted on continuously cropped land (*100*).

Advantages and Disadvantages of Fallow

Both wind and water erosion are serious problems on land fallowed for spring grains (21-month period), because the land is usually bare over the second winter of fallow. When winter small grains follow fallow (14-month period) and good growth is obtained in the fall, erosion is not so severe as with spring grains on fallow.

Although yields of spring wheat after fallow have generally not been twice as high as those on continuously cropped land, the yield advantage of fallow does not need to be this great to be considered economical, at least from the immediate needs of the farmer. However, soil erosion and its associated problems have not been included in the

TABLE 2.6.—*Water-use efficiency of spring wheat from harvest to harvest in alternately cropped and fallowed and annually cropped systems at several locations in the northern Great Plains*

State, location, and reference	Yield period	Precipitation (inches)	Water-use efficiency-bu/inch	
			Fallowed land	Wheat stubble land
Montana:				
Havre (*57*)	1917 to 1951	11.6	0.67	0.69
Moccasin (*57*)	1909 to 1951	15.0	.54	.78
Huntley (*57*)	1913 to 1951	12.8	.58	.66
Froid (*1*)	1941 to 1947	12.6	1.13	1.91
North Dakota:				
Williston (*72*)	1910 to 1920	14.7	.61	.96
Dickinson (*31*)	1908 to 1951	15.6	.67	.74
Hettinger (*72*)	1912 to 1922	14.5	.58	.80
Mandan (*31*)	1915 to 1948	15.8	.66	.94
Langdon (*43*)	1941 to 1952	19.1	.74	1.06
Edgeley (*43*)	1941 to 1953	18.0	.63	.99
Minot (*43*)	[1] 1947 to 1956	16.4	.80	1.12
South Dakota:				
Newell (*76*)	1909 to 1948	16.1	.66	.84
Ardmore (*68*)	1913 to 1930	16.6	.62	.72
Highmore (*90*)	1942 to 1955	18.4	.60	.72
Wyoming, Sheridan (*65*)	1918 to 1950	15.4	.80	.96
Mean		15.5	.69	.93

[1] Yields from only 5 years used.

cost of summer fallowing in the past. Erosion not only causes the direct loss of soil (which is essentially irreplaceable) and nutrients from the land but also deposits soil in road ditches, fence rows, windbreaks, reservoirs, streams, and around farm and city buildings, and the cost of removal is high. Crops adjacent to eroding fallow are sometimes damaged or completely destroyed. Dust blowing across highways causes accidents, and the air is sometimes so polluted with dust that breathing is difficult for both man and animals. At the present time in North Dakota, dust from wind erosion and sediment from water erosion associated with summer fallowing are the greatest respective sources of air and water pollution.

The public is becoming increasingly conscious of the significance of erosion, and will eventually demand that wind and water erosion either be controlled or that fallow be eliminated, not only from the standpoint of its effect on our soil and water resources but from the standpoint of air and water pollution.

Problems associated with summer fallow for spring wheat production in the northern Plains, compared with annual cropping, are as follows:

1. Greatly increased wind and water erosion of soil.
2. Increased air and water pollution.
3. Lower soil-water storage efficiency.
4. Lower water-use efficiency.
5. Greater soil-fertility decline.
6. Promotes development of saline seep areas under certain soil and management conditions.

The advantages of summer fallow over annual cropping for spring wheat production are:

1. Higher yield per planted acre.
2. More stable production.
3. Higher soil-water content.
4. Greater supply of available nitrogen in the soil.
5. Aids in the control of weeds.
6. Aids in distributing the work load of the farmer.
7. Reduce insect and disease problems.

Alternatives for Fallow

Results of longtime research show that summer fallow is being used in many areas of the northern Great Plains for spring wheat production where it cannot be justified from yield increase alone. Experimental results during the past 15 years indicate that fertilizers can reduce the yield advantage of fallow in some areas. In addition, intertilled crops, such as corn and sorghums, are excellent crops to precede spring wheat, and the seedbed they provide acts as a partial substitute for fallow. Where the corn or sorghum can be used on the farm, the forage or grain produced generally more than offsets the yield reduction of the following spring wheat crop in comparison to alternate spring wheat and fallow. However, soil nitrogen losses from row-crop land are high, and, when row crops are included in the rotation with small grains, the decline in total soil nitrogen is similar to that from alternate small grain and fallow. Soil losses from row crop land by wind and water erosion may also be high.

An average of 19 percent of the precipitation received during the 21-month fallow period is stored in the soil compared with 32 percent from harvest to seeding time in an annual cropping system. Both systems are extremely inefficient and emphasize the need for improved water conservation methods. Generally, sufficient water is received to produce good crops annually, if most of it could be stored and used by economic crops. If the storage efficiency during the 9 months from harvest to seeding time in an annual cropping system could be increased from the present 32 percent to at least 54 percent, then as much water would be stored in the soil as at the end of a 21-month fallow period. One source of water that is not being fully utilized in the northern Great Plains is snow (*107*). Studies with grass barriers (*16*), and level benches with nonharvested grass on the dikes (*51*), indicate some of the possibilities for increased snow collection and overwinter soil-water storage. With improved water-storage efficiency in an annual cropping system and the addition of adequate fertilizer, the acreage of fallow could be materially reduced.

One of the primary questions that needs to be answered regarding summer fallowing is, "Are there better uses for the 14 million acres of good cultivated land lying fallow each year in the northern Great Plains, not only from the standpoint of present needs but also of future needs?" If the acreage of fallow were reduced, then that not needed for crop production could be seeded to grass for livestock grazing, game refuges, or recreational areas and parks, and the soil held in place and preserved for posterity. However, some means of reimbursing the land owner would be needed. If such a program were followed, the food and fiber needs of the populace would still be met as well as the needs for recreational areas and a more healthful environment.

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CHAPTER 3.—SUMMER FALLOW IN THE NORTHERN GREAT PLAINS (WINTER WHEAT)[1]

A. L. Black, F. H. Siddoway, and P. L. Brown[2]

Introduction

At Indian Head, Saskatchewan (Assiniboia in 1885), a Scotch farmer, Angus McKay, was indirectly forced to use summer tillage on dryland (*30*). Because his farmhands quit working to fight the métis led by Louis Riel who wanted to stop the advance of mechanized civilization, McKay had no help to sow the wheat. He did, however, plow one field and managed to keep it free of weeds by periodic tillage throughout the summer. The next spring, 1886, he seeded the idle field to wheat. Much to his surprise and despite a dry growing season, the wheat yielded 35 bushels/acre in contrast to an adjacent field that yielded only 2 bushels/acre. Sometime before 1894, summer fallowing was practiced in the Gallatin Valley of Montana despite the nonsympathetic viewpoint of the Agricultural Experiment Station (*23*).

However, it was not until nearly a quarter of a century later, when the Montana homestead rush began, that the "miracle of summer fallow" spread into the Plains area. Some of the more shrewd and less impatient newcomers adopted summer tillage. During the prolonged drought from 1912 to 1921, the practice of summer fallow was being adopted. In most of the northern Great Plains, some of these years of record drought still hold. By 1917 the dust clouds had become bigger and blacker. Summer fallow failed, even on farms where it had previously been successful.

Meanwhile, a second "miracle" was forthcoming from the Nobleford-Monarch section of Alberta (*30*), where two brothers, Leonard and Arie Koole, watched the wind blow the topsoil from their fallowed fields in 1917—the first of the four great drought years that "drove out" many Montana homesteaders. Someone observed that the westernmost edges of the fields broadside to the wind did not drift and that the "blow" did not start until the wind had swept some distance into the fields. Thus, the need for more western edges on a field was visualized. Why not "narrow" the fields by establishing alternate strips of crop and fallow? The Koole brothers tried it in 1918. It worked, and strip-crop farming was to become the salvation of the northern Great Plains. Within 2 years, some Montanans had heard about the practice and began crusading for its application. In some areas, groups, such as strip-farming clubs, worked together so effectively that alternate crop-fallow strips extended from one farm to the next; this prevented the occurrence of two fallow strips lying side by side. Farmer acceptance of stripcropping as a practice to conserve water and control wind erosion spread rapidly. Incentive payments by the Government further hastened its spread in the 1930's.

Climate

The northern Great Plains climate is distinctly continental in character. Both temperature and precipitation extremes are common. Fall and winter (September to March) precipitation across the area is low, averaging about 3.3 inches, with 2.0 inches received from snow. March and April precipitation averages about 2 inches, but northeastern Montana receives about one-fourth inch less than north-central Montana. June precipitation (3.0 inches) accounts for about 40 percent of the total growing season precipitation. July and August precipitation increases from about 2.7 inches in north-central Montana to about 3.4 inches in northeastern Montana. June, July, and August temperature means are 4° F. warmer, and December, January, and February temperature means are 9° F. cooler at Culbertson than at Conrad, Mont. (see fig. 2.1

[1] Contribution from the Agricultural Research Service, USDA, in cooperation with the Montana Agricultural Experiment Station.

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for location of towns). These differences in precipitation and temperature patterns between the two towns, which are representative of land resource areas 52 and 53, respectively, are important in relation to the adaptation of the major crops grown—predominately winter wheat in the north-central area, and spring wheat and some corn and oilseed crops in the northeastern area (*48, 49, 50*).

Wide variations in annual precipitation are common as shown by the long term weather records (70 years, or more) of three typical northern Great Plains weather stations at Circle, Poplar, and Havre, Mont. (*48, 49, 50*). Figure 2.1 shows the location of towns in relation to land resource areas represented. At Circle, annual precipitation has ranged from 5.21 inches in 1934 to 28.23 inches in 1921; at Poplar, from 6.34 inches in 1917 to 25.35 inches in 1906; and at Havre, from 6.76 inches in 1905 to 25.67 inches in 1884. Neither the lowest nor the highest annual precipitation ever recorded at these three locations occurred the same year. The average annual precipitation for Circle, Poplar, and Havre is 11.6, 12.6, and 11.2 inches, respectively. Annual precipitation for these same locations can be expected to average more than 15 inches in 1 of 4 years but less than 10 inches in 1 of 5 years.

Wide variations in monthly precipitation are also common. For instance, June precipitation at Circle has ranged from 0.52 inch in 1919 to 16.79 inches in 1921. Of this June 1921 total of 16.79 inches, 11.50 inches fell during a 24-hour period ending at 6 p.m. on June 21. This is the largest 24-hour precipitation ever recorded in Montana. June precipitation at Poplar has ranged from 0.39 inch in 1919 to 7.32 inches in 1921, and at Havre, from 0.24 inch in 1889 to 9.33 inches in 1887.

March, April, and May temperatures are extremely variable from year to year. An advancing mass of cold polar air may displace warm tropical air, bringing about a drop in temperature of as much as 50° F. in a few hours. Air temperatures in June, July, and August frequently reach 100°. The absolute minimum and maximum temperatures recorded at Poplar, Mont., are −63° and 110°—a range of 173°.

High wind velocities of relatively short duration may occur in any month of the year, but most of the prolonged windy periods occur in March, April, and May. During the spring, winds of 30 to 40 miles per hour for several days in succession are common. Consequently, nearly every year in certain localized areas, some soil blowing on winter wheat land occurs, and a certain amount of spring grain is reseeded, particularly on sandy soils. The frost-free growing season for the northern Great Plains ranges from about 90 to 130 days.

Soils

In the northern Great Plains, winter wheat is produced mostly on soils classified as Argiborolls and Haploborolls. These soils are mainly dark in color and high in bases. They are cool, well-drained soils of regions with continental climates. The mean annual soil temperature at 20 inches does not exceed 47° F. The mean summer soil temperature is between 60 and 70°, and the mean annual precipitation ranges from 10 to 20 inches. In the drier soils, lime has accumulated at a depth of about 6 inches; whereas, in soils receiving higher rainfall, lime has been leached as deeply as 5 feet. Most of the soils used for winter wheat production have been formed on glacial till and other deposits of late Pleistocene age. Slopes are usually gentle to moderate.

Argiborolls, the predominant group of soils, have prismatic- or blocky-structured subsoils (B horizons) enriched in clay. Clay enrichment is less pronounced in the Haploborolls. Winter wheat is produced on both Typic and Aridic subgroups of these soils. The more abundant Typic subgroup is moist more than half of the time in part of the 4- to 12-inch-depth zone when the soil is warmer than 41° F. Most of these were listed as Chestnut soils in the 1938 classification system (*2*). Aridic subgroups, by contrast, are usually dry in the 4- to 12-inch zone during most of the growing season. These were formerly called "Brown" soils. Some winter wheat is grown on Cryoborolls, which were formerly called "Chernozem," soils. These soils are darker, deeper, and have a mean summer temperature of less than 59° at a depth of 20 inches. Detailed soil surveys are still lacking in many areas of the northern Great Plains. For example, in Montana as of June 30, 1968, detailed soil surveys had been completed in only five counties and only three had been published. In 30 of the major small grain-producing counties of the State, detailed soil surveys have not been completed or, in some instances, not even started (*37*). For this reason, reconnaissance surveys dating back to the late 1920's and early 1930's constitute the only soils information currently available in most counties.

Crops and Cropping Practices

The major crops of the northern Great Plains, listed in decreasing order of acreages harvested are: Hard red spring wheat, hard red winter wheat, barley, durum spring wheat, oats, corn, and miscellaneous crops (*47*). Nearly all the winter wheat and most of the barley acreages in the northern Great Plains are planted on fallow. Corn, oats, and some barley are frequently seeded on nonfallowed land in variable cropping sequences.

In the northern Great Plains, winter wheat occupies about 3.3 million acres (*47*), 74 percent of which is in Montana; 20 percent, in South Dakota; 3.5 percent, in North Dakota; and 2.5 percent, in northern Wyoming. (See fig. 1.8 for a map of the northern Great Plains region and fig. 1.5 for the winter wheat-producing regions of the United States.) The acreage of winter wheat has gradually increased from about one-half million in 1938 to over 3 million in 1969; and since 1965, the acreage of winter wheat in Montana has exceeded that of spring wheat (*12*). This increase has resulted from improved tillage and seeding equipment, better crop-residue and soil-management practices, improved varieties with greater winter hardiness, and higher yields. Barley acreages in Montana have increased from about one-half million in 1952 to 2 million in 1969. Fallow acreages have also increased in Montana; in 1930, fallow acreages totaled about 2.8 million; in 1950, 4.2 million; and in 1964, 6.0 million (*46*).

The major winter wheat-producing region in the northern Great Plains is the "Triangle Area" of Montana, which corresponds with land resource area 52 (fig. 2.1). Winter wheat is also the major crop grown on the limited acreage of land resource area 59, and it is grown to some extent in land resource areas 54, 58, and 63 (see figs. 1.5 and 2.1). However, because spring wheat can be substituted for winter wheat when necessary or warranted in the major part of the northern Great Plains, some flexibility in cropping sequences is available. In addition, the integration of livestock into many farming operations over the past 20 years, and the resultant high demand for feed grains and forage crops, has provided some additional flexibility in cropping sequences for many farmers. Both winter wheat and spring wheat are now grown in every county in Montana.

Winter wheat is seeded on fallow with a semideep-or deep-furrow hoe drill, either alone or in combination with a seedbed-tillage implement, usually between August 25 and September 25. Row spacings for winter wheat range from 10 to 14 inches. Winter wheat is harvested the next year, usually between July 20 and August 25.

A typical time sequence for periods of fallow, planting, crop growth, and harvesting for winter wheat production is:

Time	*Field operations or conditions*
July 20 to August 25	Harvest wheat
August 25 to May 10	Standing wheat stubble (overwinter period)
May 10 through August 25	Cultivate summer fallow
August 25 to September 25	Plant wheat
September 25 through March 15	Dormant period
March 15 to July 20	Wheat growth
July 20 to August 25	Harvest wheat

Fallow operations are not traditionally performed on standing-stubble fields after harvest in the fall. Standing wheat stubble catches blowing snow, which aids soil-water storage during fallow (*10*). However, some stubble fields may be fall tilled with small-blade, or chisel-type, implements if postharvest precipitation causes weed growth. The first fallow operation is normally performed in May, and the type of implement used is governed largely by the soil conditions and amount of crop residue present at that time. Tillage implements with small sweeps 10 to 18 inches wide, or large sweeps up to 8 feet wide, are often used for the first operation when crop-residue levels are less than 4,000 lb./acre. If the crop-residue level at the beginning of fallow exceeds 4,000 lb./acre, a disk-type implement is often used to chop the straw into shorter lengths and to incorporate from 30 to 50 percent of it into the soil. Successive tillage operations on fallow usually are performed with small sweep-type cultivators, with or without a rod weeder attachment. A rod weeder is the predominant tillage implement used for the last fallow operation before seeding winter wheat. The number of tillage operations per fallow season varies from three to six, but the average is four or five.

Water Conservation

Soil-water recharge during fallow is influenced primarily by climate, soils, tillage, soil fertility, the previous crop, and the quantity of crop residue maintained on the soil surface during fallow. Research (*8*, *10*, *25*, *26*) shows that current stubble-mulch fallow methods store precipitation more efficiently than previous methods (*1*, *21*, *31*, *35*). Typically, total soil-water storage during 14 months of fallow for winter wheat varies considerably with years (table 3.1) (*8*, *10*, *25*, and A. L. Black, Sidney, Mont., unpublished data). For instance, precipitation varied from 2.4 to 9.6 inches during a 14-year period at Sidney, Mont., and soil-water storage ranged from 1.3 to 4.3 inches. The percentage of overwinter precipitation stored in the soil (storage efficiency) ranged from 35.4 to 153.6 percent, averaging 71.4 percent over the 14-year period. Overwinter storage efficiencies were unrelated to total overwinter precipitation, but poor efficiencies were associated with years of above-average late fall precipitation. During the summer of fallow, precipitation ranged from 3.8 to 13.5 inches and soil-water storage ranged from a loss of 0.9 inches to a net gain of 2.7 inches. During this period, storage efficiency ranged from a loss of 11.1 percent to a gain of 25.0 percent. The overall storage efficiency for the summer of fallow averaged only 5.9 percent for the 14-year period.

Utilizing the data presented in table 3.1, total soil water-storage efficiency during the entire fallow period was negatively correlated with fallow precipitation ($Y = 52.1 - 0.69X$, $P = 0.05$). The average fallow precipitation received was 13.4 inches; and, for each additional inch of water received above this amount, fallow efficiencies were reduced 3.3 percent.

Storage efficiencies reveal very little regarding the actual amount of water stored in the profile. Examination of the data given in table 3.1 by individual years shows that soil water was conserved consistently during each summer of fallow if overwinter precipitation the previous 9 months was below average. However, if overwinter precipitation the first 9 months of fallow was above average, then soil water during the summer of fallow was actually lost or the gain was very small. The decision to summer fallow or to recrop (to spring small grain or a row crop) could be based on the amount of soil water at seeding (*8*).

In the northern Great Plains, about 25 percent of the annual precipitation is received during the winter months. Only recently has a concentrated research effort been made to efficiently utilize winter precipitation to supplement stored soil water.

TABLE 3.1.—*Soil-water storage, precipitation, and soil-water storage efficiencies by years with conventional stubble-mulching*

Year	Soil water stored, inches			Precipitation, inches			Storage efficiency, percentage		
	Over-winter	Summer of fallow	Total	Over-winter	Summer of fallow	Total	Over-winter	Summer of fallow	Total period
1957	4.0	0.6	4.6	6.1	6.5	12.6	65.5	9.2	36.5
1958	4.0	−.3	3.7	8.1	3.8	11.9	49.4	−7.9	31.1
1959	2.8	.8	3.6	5.0	7.6	12.6	56.0	10.5	28.6
1960	4.3	.0	4.3	2.8	6.9	9.7	153.6	0	44.3
1961	1.3	1.8	3.1	2.4	7.2	9.6	54.2	25.0	32.3
1962	3.3	2.7	6.0	4.3	13.5	17.8	76.7	20.0	33.7
1963	3.9	−.3	3.6	5.6	9.5	15.1	69.6	−3.2	23.8
1964	3.5	−.9	2.6	6.7	8.1	14.8	52.2	−11.1	17.6
1965	3.7	−.6	3.1	3.0	12.0	15.0	123.3	−5.0	20.7
1966	2.5	.6	3.1	2.8	5.0	7.8	89.3	12.0	39.7
1967	2.4	.8	3.2	3.9	8.3	12.2	61.5	9.6	26.2
1968	1.9	2.5	4.4	3.4	11.9	15.3	55.9	21.0	28.8
1969	2.7	.4	3.1	4.8	8.1	12.9	56.3	4.9	24.0
1970	3.4	−.2	3.2	9.6	10.5	20.1	35.4	−1.9	15.9
Mean	3.1	.6	3.7	4.9	8.5	13.4	71.4	5.9	27.6

SOURCE: (*8*, *10*, *25*, and A. L. Black, Sidney, Mont., unpublished data.)

Annual vegetative barriers with 37-foot intervals between double rows were tested at Akron, Col., and Sidney, Mont. for effective snow-trapping and distribution potentials (*11*, *24*). During the first overwinter (9-month) period at Sidney, snow trapped within double-row barriers of tall wheatgrass (*Agropyron elongatum*) spaced at 30- or 60-foot intervals, increased soil-water recharge enough to equal 14 or 21 months of fallow (*11*). This indicates that snow is an extremely important source of soil water in the northern Great Plains. Infiltration and storage of snowmelt water is largely controlled by the water content of the upper 2 feet of soil at the time the soil freezes in the fall (*51*). Consequently, any cropping or tillage practice that would enhance infiltration of snowmelt would increase the efficiency of soil-water storage. Even though some studies concerning snow management are now underway in the northern Great Plains, considerable research is still needed to better understand the relationship of soil texture, slope, and cropping sequences to soil-water storage of winter precipitation, as influenced by crop-residue and soil-management practices.

To date most research has shown that tillage *per se* does not significantly influence soil-water storage during fallow (*1*, *32*, *40*). However, these early studies for the most part involved merely a comparison of one tillage method with another; consequently, it was not possible to determine whether the amount of soil water stored during fallow was influenced by the soil physical effects created by the different tillage implements or by the amount of stubble present, or both. Field studies involving only sweep tillage have clarified the effect of defined quantities of wheat-straw mulch on soil-water storage during fallow (*6*, *25*, 26). In these studies, soil-water storage increased in proportion to the quantity of straw maintained on the soil surface during fallow; therefore, it can be concluded that those tillage implements that conserve surface residue also conserve soil water.

Complete chemical fallow for spring wheat—no tillage except during seedbed preparation—failed to conserve as much soil water as conventional stubble-mulch tillage, even when adequate weed control was obtained with chemicals (*10*). Among the combinations of chemical- and mechanical-fallow methods tested, one or more tillage operations were necessary to prevent capillary losses of water from the soil surface through evaporation. Although some of the combinations of chemical- plus mechanical-fallow methods tested were as effective in storing soil water as conventional stubble-mulch fallow, none were superior (*10*).

Another important aspect of soil-water conservation during fallow is the effective depth and total quantity of soil-water extraction by the previous crop. Obviously, the more water extracted by crops from the storage reservoir each year, the more precipitation needed to recharge the profile during fallow. Brown (*13*) has shown that fertilization, particularly with relatively high rates of nitrogen, greatly increased the depth of soil-water extraction by winter wheat. Fertilized wheat used nearly twice as much total soil water as the check. After fallowing, if both the unfertilized and fertilized soil profiles were completely recharged, the efficiency of fallow was considerably higher for the fertilized soil profile. Soil-management and cropping practices that effectively increase soil-water extraction greatly enhance fallow efficiency. Soil-water extraction is one of the most important aspects of any cropping system that involves fallow. For example, winter wheat consistently extracts all available soil water to a depth of 5 to 6 feet, but spring wheat seldom extracts soil water below 3 feet (*9*, *13*). Therefore, summer fallowing for winter wheat is usually more efficient in conserving precipitation than summer fallowing for spring wheat, irrespective of the different fallow-period lengths—14 and 21 months, respectively—for winter wheat and spring wheat.

Bauer (*3*) compiled a cumulative monthly precipitation curve for four geographic areas of North Dakota based on the 1930–67 precipitation records. After evaluating the growing-season rainfall, soil-water storage for fallow and nonfallow, and also spring wheat yields with and without fertilization, he concluded that only in the western one-third of North Dakota could a wheat-fallow system be expected to be more profitable than a wheat-wheat system of cropping, and then only with adequate fertility. From Bauer's analysis, when cumulative annual precipitation is less than 15 inches, fallowing is economical.

The alternate crop-fallow system so widely practiced in Montana and North Dakota is producing some adverse results (*20*). During the past decade, saline-seep areas have developed on the hillsides, gentle slopes, and drainageways of certain agricultural lands. Farmers are greatly concerned about these seep spots, because removing the affected land from cultivation makes the surrounding area more difficult to farm. Furthermore, once a seep spot develops, it expands rapidly and may cover several acres. Such seep spots are appearing in cultivated fields of northcentral and northeastern Montana, western North Dakota, and southern Canada.

The problem stems from the geology of the region, the farming practices, and surplus water moving through the soil profile. The surface material is glacial till, 2 to 60 feet thick, underlain by impermeable shale (Colorado and Bear Paw geologic formations) and clay layers, or intermittent lignite layers. Crops on the arable land are generally winter wheat, spring wheat, or barley in an alternate crop-fallow sequence. Annual precipitation ranges from 13 to 18 inches in the problem areas, but may exceed 20 inches some years. Evidence indicates that cereal crops grown in alternate years fail to extract all of the water stored during fallow. The excess water moves downward to impermeable parent material or shale layers, and then downslope. In many places, a water table exists. The water has a high salt content because of the salt content of the deep subsoil, parent material, and shale. The salts are chiefly sodium and magnesium sulfates. The impermeable parent material and shale layers approach the soil surface at some distance downslope. When the water comes to within 4 to 5 feet of the surface, a salt-seep area may start; and once started, it expands rapidly.

The most reasonable solution to the problem is to use the water for crop growth before it penetrates beyond the root zone. This means annual cropping, or at least more intensive cropping, and limited use of fallow. Establishing perennial grasses or planting a deep-rooted crop such as alfalfa may help control the development of saline-seep areas. However, these crops should be adequately fertilized to encourage deep rooting.

The Montana Agricultural Experiment Station, Montana Cooperative Extension Service, and the Montana Bureau of Mines and Geology, cooperating with three agencies of the U.S. Department of Agriculture—the Economic Research Service, Soil Conservation Service, and Agricultural Research Service—initiated limited research on the problem in the Highwood Bench area of Montana in 1969. The same year Agricultural Research Service personnel from Mandan, N. Dak., initiated research on this problem at Mott, N. Dak.

The foregoing discussion shows that the conservation of an extra increment of water is not necessarily the unmixed blessing it was once believed to be. Miller (*36*) has pointed out that saline-seep areas could potentially cover large areas in the northern Great Plains and Canada. Surface till of various thicknesses, underlain by thick sequences of black marine shale of late Cretaceous age, cover thousands of square miles in Montana, North Dakota, South Dakota, and the prairie provinces of southern Canada. In February 1971, Clark reported that the saline-seep problem has already affected 81,340 acres of cropland in 25 of the major wheat-producing counties in Montana (*20*).

Erosion

Wind

Wind erosion occurs when the soil is finely divided and loose, the soil surface is smooth, bare, and dry, and wind velocity is sufficiently high. These conditions become increasingly serious as the size of field increases from narrow to broad, because wind erosion is an "avalanche" phenomenon; that is, the rate of soil movement increases from the windward to the leeward edge of a field. This rate of increase across a smooth, bare field is primarily dependent on soil texture. With a wind of about 20 miles per hour at a height of 1 foot above ground level, sand reaches its maximum rate of flow at a distance of 100 feet from the windward edge of a field; loamy sand, at 168 feet; sandy loam, at 917 feet; loam, at 2,366 feet; clay loam, at 3,300 feet; and clay, when subject to granulation from weathering, at 717 feet (*15*).

Wind stripcropping, the first control method for wind erosion in the northern Great Plains, makes use of the avalanche phenomenon by breaking large single-culture fields into narrow, alternate strips of crop and fallow. As presently designed, wind strips vary in width from as narrow as 50 feet for sandy soils to over 300 feet for less erosive medium-textured soils.

Stripcropping continues to be the foundation of wind-erosion control but has been augmented during the past two decades with stubble-mulch tillage.

The level of protection afforded by stubble mulching is proportional to the amount of crop residue maintained on the soil surface. Winter wheat, because of its high yield capacity and straw:grain ratio of about 2:1, supplies more residue for protection against wind erosion than spring wheat, which has a lower yield capacity and straw:grain ratio of about 1.3:1. For example, in 1970 straw production in Montana averaged about 3,200 pounds/acre for winter wheat and only about 1,800 pounds/acre for spring wheat. Typically, operations with subsurface tillage equipment reduce residue quantity about 50 percent by the end of the summer-fallow period. The quantity remaining for wind-erosion control at the end of the fallow period is generally adequate after winter wheat, but is often inadequate after spring wheat. In addition, the fallow period for spring wheat includes two winters, whereas that for winter wheat includes only one. Each tillage operation also reduces the proportion of nonerodible soil aggregates, which makes the soil more erodible as the fallow season progresses (*10, 43*). Combinations of chemical- and mechanical-fallow methods conserve more residue and more nonerodible clods than conventional tillage; but under sparse precipitation, adverse residual effects of present herbicides make the combination method impractical (*10*).

Despite the relatively good control afforded by stripcropping and stubble-mulch tillage, wind erosion remains a problem because of localized drought, improper tillage practices, and the inherent erodibility of sandy soil. Table 3.2, showing cropland damaged by wind erosion in the northern Great Plains during the 1966–67 through 1969–70 wind-erosion seasons, indicates the severity of the problem and the need for more intensive control measures. For example, the Soil Conservation Service estimates the need for an additional 3.3 million acres of residue and annual cover and 2.9 million acres of stripcropping to achieve the desired level of erosion control in Montana. Wind-erosion forces are high in the northern Great Plains from October through April (*44*). Snow cover offers intermittent protection during the winter months, but winter wheat is especially vulnerable to erosion during March and April, and seedbed preparation for spring-seeded crops presents an additional hazard.

A new control method for wind erosion (*11*), double-row wheatgrass barriers spaced at 30- and 60-foot intervals across a field, has the potential of controlling wind erosion on the approximately 5 million acres of cultivated sandy soils in the northern Great Plains (*16*).

Thus, although summer fallow is almost synonymous with wind erosion in cultivated dryland agriculture, fallowing in the drier areas of the northern Great Plains does add a degree of stability to crop production. Where winter wheat is grown, fallow improves the probability of producing sufficient crop residue to protect the soil from erosion. Intensive cropping systems involving a crop-fallow ratio of 2:1 or 3:1 would expose large blocks of land to the erosive forces of wind during seedbed preparation or during successive drought years. On the other hand, intensive cropping during years of average or above-average rainfall would protect more land with vegetative cover, thereby lessening the severity of the erosion hazard.

TABLE 3.2.—*Cropland damaged by wind erosion in the northern Great Plains from 1966 through 1970*

Season	Cropland damaged by wind erosion (1,000 acres)				
	Montana	North Dakota	South Dakota	Wyoming	Total
1965–66	46	127	91	17	281
1966–67	131	198	180	25	534
1967–68	149	443	25	16	633
1968–69	78	223	36	13	350
1969–70	259	528	70	49	906
Total	663	1,519	402	120	2,704

SOURCE: Wind Damage Reports of the USDA, Soil Conservation Service, unpublished information.

Water

Water erosion is a problem on the gently to steeply rolling cultivated lands of the northern Great Plains. Summer fallowed land is susceptible to erosion from both snowmelt runoff and intense summer rains. Erosion losses are generally small from land in either stubble or crops, but runoff from these areas onto adjacent summer fallow is an insidious process and is additively serious, particularly on shallow soils. Erosion from snowmelt runoff occurs over the whole region when the rate of snowmelt exceeds the infiltration capacity of frozen soils. Erosion is usually not severe in any one year but is limited primarily to natural drainageways. On the other hand, intense summer rainstorms, though spatially limited, cause extreme damage in localized areas each year. Recorded rainfall intensities for ½-, 1-, and 24-hour periods in the northern Great Plains have been as high as 2.4, 3.0, and 5.0 inches, respectively (*33*). When rainfall of this intensity occurs on fine- or medium-textured summer-fallowed land, the resulting erosion may exceed the total of all past erosion since the land was brought under cultivation.

Stubble-mulch farming, contour stripcropping, grassed waterways, and conservation bench terracing are conservation practices used to control water erosion. Of these practices, stubble mulching is by far the most widely used. The mulch intercepts the direct impact of raindrops and tends to prevent dispersion of the soil surface; thereby, a relatively high infiltration rate is maintained (*34*).

Data from Sidney, Mont.,[3] indicate the possibility of improved soil structure resulting from stubble-mulch tillage. At the beginning of fallow, plots with established wheat-straw levels of 0, 2,000, 3,000, and 6,000 lb./acre were sampled at the 0- to 2-inch depths, and the percentage of dry soil aggregates of various size fractions was determined after four complete wheat-fallow cycles. As wheat-straw levels increased in the order given above, the percentage of aggregates greater than 0.033 inch in diameter was 53, 57, 64, and 77 percent, respectively. The larger pore space associated with the larger clods would favor high infiltration and less erosion.

Contour stripcropping is usually designed with equal-width strips of crop and fallow and variable-width grass-buffer strips to compensate for topographic irregularities. Contour strips shorten slope length, which thereby helps to prevent erosive channeling of concentrations of runoff water. Although this practice is effective, especially in combination with stubble mulch, the acreage devoted to contour strips is relatively small. Level bench terracing (*52*) is the only erosion-control system that affords nearly complete protection against water erosion, but the moderately high cost of construction and the inconvenience of using large-scale equipment in narrow benches have limited the adoption of this conservation practice. Grassed waterways are natural drainageways that serve to nonerosively transport final concentrations of runoff water from fields. Although grassed waterways do nothing to control erosion from the field, they do prevent deep gullying in natural drainageways and permit the farmer to cross them with his implements.

[3] A. L. Black. ANNUAL RESEARCH REPORT. Northern Plains Soil and Water Res. Center, Agr. Res. Serv., U.S. Dept. Agr. Sidney, Mont. 1970.

Soil Fertility

Regardless of the cropping system used or the crops grown, soil fertility is an important aspect of efficient dryland farming. The use of fertilizer in the northern Great Plains has increased about 300 percent. In Montana, the use of fertilizer increased from a total of 45,000 tons in 1960 to 141,000 tons in 1967 (*29*). A preliminary estimate of the tons of fertilizer used in Montana in 1970 is 178,000 (*28*). Use of fertilizer has increased similarly in North Dakota, South Dakota, and Wyoming (*28*). The major part of this increase can be ascribed to an increase in the use of fertilizer for small-grain production on dryland.

Fertilization practices for wheat grown on fallow in the northern Great Plains has centered primarily around nitrogen (N) and phosphorus (P) requirements. In some cases, fallowing reduces the need for fertilization, particularly N (*3*, *4*). In other cases, where soil NO_3-N values range from 10 to 40 lb./acre after fallow, the extra stored water increases the yield potential and the need for N fertilization. Fallow encourages the release of considerable quantities of soil NO_3-N, but time of tillage and quantity of residue on the surface or incorporated into the soil greatly modify not only the time of NO_3-N release but also the quantity released (*45*). Surface-mulch levels in excess of

3,000 lb./acre significantly reduce total soil NO_3-N accumulation during fallow.

Glacial-till soils of western North Dakota and eastern and north-central Montana are generally deficient in available P (*7*, *9*, *41*, *42*). Management of wheat-stubble residue influences availability of both N and P (*53*). Using four different wheat-straw levels at the beginning of fallow, Black [A. L. Black, unpublished data] determined the long term effect of wheat straw on soil P availability. As measured by the $NaHCO_3$ method of extraction (*39*), soluble P for the 0-, 2,000-, 3,000-, and 6,000-lb./acre straw levels after 8 years was 3.9, 5.4 5.6, and 5.9 p.p.m., respectively, with no P added, and 6.7, 7.3, 9.3, and 9.3 p.p.m., respectively, where a total of 60 lb. of P per acre had been applied. With or without added P, grain yields increased as residue levels increased, because of the associated increase in stored soil water and soil P availability. Therefore, fallow methods that conserve crop residue tend to increase soil P availability.

Soil organic matter, nitrogen, and carbon have decreased with years of cultivation and cropping practices (*27*). Fallow and row-crop farming accelerate the loss of soil N and C, compared with continuous cropping. Because of this, fertilizer responses are now being obtained rather consistently each year on most soils, irrespective of fallow, under average soil-water and precipitation regimes. Total soil nutrients removed in the harvested part of crops grown under a crop-fallow or continuous-cropping system have been about the same (*27*). Loss of nitrogen from fallow has resulted primarily from loss of soil through wind and water erosion; but in years of above-average precipitation, some additional N loss may have occurred through leaching below the root zone or through other ways, such as volatilization.

Crop Yields

Increase From Fallow

In Montana, yields of winter wheat on fallow averaged only 16.5 bushels/acre for the 1929–51 period, compared with 24.9 bushels/acre for the 1952–70 period, even though the two periods were similar with respect to climatic conditions—both periods had about the same number of dry, normal, and wet years (*38*). This 1.5-fold yield increase that has occurred since 1952 reflects the overall influence of improved agricultural technology. In addition, the 1969 Yearbook of Agriculture attributes the nationwide 1.7-fold increase in wheat yields to new and improved technology; since 1950, yields in the United States have increased from 16.5 to 28.4 bushels/acre (*22*).

Obsoleted by new technology, but nevertheless a matter of record, are the yield data of winter wheat obtained before 1951 from fallow and continuous cropping at Havre, Moccasin, and Huntley, Mont. (*31*) and Dickinson, N. Dak. (*21*). In these "old" dryland rotation studies, yields from continuous cropping averaged only 39 percent of those obtained from fallow. Figure 3.1 shows the yield-probability level of continuous winter wheat versus winter wheat grown on fallow for the 1917–51 period at Havre, Mont. (*31*). In the 10 to 70 percent range, yields of wheat on fallow at any given probability level were more than double those from continuous winter wheat. However, the use of new and improved agricultural technology has increased yields under both cropping systems. Since 1948, herbicides, fertilizer, and seed treatments all have established an important place in dryland crop production and, combined with improved crop varieties, farm equipment, and soil-management practices, have made continuous cropping much more feasible.

Crop rotations involving corn, such as corn-wheat, corn-wheat-corn-barley, and wheat-corn-barley-fallow, have been much more efficient than continuous wheat (*17*, *21*, *31*). Average wheat yields after corn were reduced only 3 to 5 bu./acre compared with yields from fallow; this indicates that corn can be a good substitute for fallow. Studies at Moccasin, Mont. (*19*) show the importance of crop rotations in conjunction with fallow. Nine years of results show that wheat yields from fallow averaged 32 bu./acre in a wheat-fallow rotation and 39 bu./acre in a wheat-barley-fallow rotation. Yields from the wheat-barley-fallow rotation were higher than those from wheat-fallow, because including barley in the cropping sequence helped control downy bromegrass and, perhaps, certain plant diseases, too.

Owing to new or improved technology, wheat yields now obtained after fallow are higher than those of previous years. These higher yields have, in turn, effected increases in: (1) Total soil-water extraction by the crop, (2) precipitation-storage

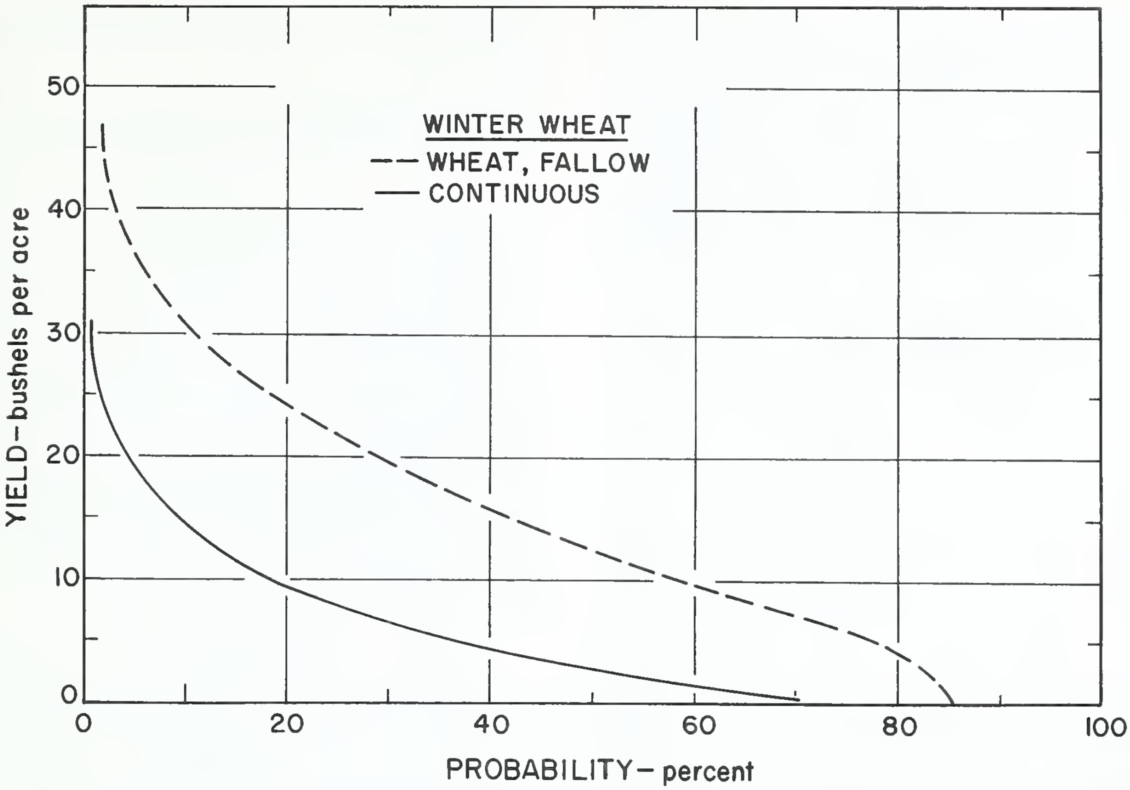

FIGURE 3.1.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at Havre, Mont., 1917–51 (*31*).

efficiency of fallow (*25*), and (3) the fallow acreage needed for wheat production in a semiarid climate. Therefore, winter wheat is nearly always seeded on fallow in a flexible cropping sequence even when the previous crop was not necessarily winter wheat.

Fertilizer Effects

A thorough knowledge of the inherent fertility status of dryland soils, crop-residue management systems, soil water at seeding, and a reasonable estimate of growing-season precipitation are needed before effective fertilizer practices can be recommended. Determination of the amount of N fertilizer that should be applied in any given year is difficult. The amount of N available for plant growth at seeding time can be determined; but the amount of N that will be released from organic sources during crop growth depends on (1) the amount of organic matter and crop residue present or incorporated at seeding time, and (2) the soil temperature-soil water interrelationships that occur during the growing season. Because soil temperature and growing-season precipitation vary from season to season and from year to year, it is extremely difficult to determine the most economical rate of N fertilizer that should be applied, regardless of the cropping system used.

Available soil P, stored soil water, and growing season precipitation all have a definite influence on the yield response of dryland wheat (*41, 42*). As available soil water decreases, the percentage of total plant P uptake derived from P fertilizer increases (*42*). Studies show that relatively high rates (rates greater than 40 lb./acre) of P fertilizer are required on a Williams loam glacial-till soil to insure maximum yields from fallow, particularly in dry years (*7, 9*). Nitrogen topdressing increases grain yields and protein content much more effectively on glacial-till soils if adequate P fertilizer has been supplied first (*7, 18*).

Wheat production on the Brown soils of the northern Great Plains is limited primarily by lack of water, as annual precipitation averages 10 to 13 inches. For this reason, responses to N, P, and N-P fertilization have been inconsistent and variable (*14*). Nitrogen topdressing studies conducted on Brown and glacial-till soils by the Montana Agricultural Experiment Station reveal that significant grain-yield increases from N-P fertilization can be expected if stored soil water is adequate and growing season precipitation exceeds 8 inches (*18*). Soil NO_3-N levels to a depth of 4 feet after fallowing must also be considered in predicting the N fertilizer requirements of winter wheat.

Unfortunately, from 1948 until about 1960, no studies involving winter wheat, with or without fertilization and modern agricultural technology, were initiated in the northern Great Plains to enable comparison of yields from continuous cropping with those from the crop-fallow system. However, such studies are being conducted at the South Central Research Farm at Presho, S. Dak.[4] For the 1960–69 period at Presho, winter wheat on fallow averaged 21.2 bushels/acre (10.6 bu./acre/year), compared with 12.0 bushels/acre from continuous cropping with no N added and only 11.8 bushels/acre from continuous cropping with annual applications of 30 pounds of N per acre (weeds were a problem). In similar studies by H. R. Houlton, R. T. Choriki, and Don Baldridge, (personnel communication), and by A. L. Black, (unpublished data), at Havre, Moccasin, Huntley, and Sidney, Mont., respectively, the average yields were: Without fertilization, on fallow about 24 bushels/acre (12 bu./acre/year) and 12 bushels/acre from continuous cropping; with adequate fertilization, on fallow nearly 30 bushels/acre (15 bu./acre/year) and 23 bushels/acre from continuous cropping.

Here again is evidence that new technology is responsible for the increased wheat yields obtained under both crop-fallow and continuous-cropping systems. But, in spite of these yield increases, researchers in both Montana and South Dakota experienced two major problems with continuous cropping. One problem was lack of soil water for stand establishment in the fall, and the other was difficulty in controlling weeds, particularly those that tend to invade annual cropping systems. Disease could be an additional problem because the incidence of specific plant diseases, such as wheat streak mosaic (*Cephalosporium* stripe), root rot (*Helminthosporium* sp.), and leaf spot (*Septoria tritici*), would be expected to increase under a continuous-cropping system. However, any of the aforementioned problems, if a problem at all, would be less severe with fallow.

[4] H. A. Giese. annual progress reports. South Central Res. Farm, S. Dak. Agr. Expt. Sta., Presho, S. Dak., 1960–69.

Crop Quality

As early as 1937, Bell (*5*) pointed out two important facts about production of winter wheat: (1) Fallow consistently produces a higher test weight and protein content than recropped land, and (2) recropped land requires relatively high rates of N fertilizer to produce and maintain protein-content and yield levels equal to those produced on fallow. Consequently, the risk of a low test weight would be less on fallow than on recropped land, especially if soil water were in short supply late in the growing season.

Summary

Advantages and Disadvantages of Fallow

How effectively a farming system prevents loss of soil water and precipitation to weeds largely determines its success or failure—whether the land is in fallow or crops. This also applies to winter wheat. The success or failure of a wheat crop, whether on recropped or fallowed land, will be determined largely by seedbed preparation in relation to adequate stand establishment and effective weed control. However, since such problems are usually seasonal or local, the farmer must solve them himself under the climatic and soil conditions present at that particular time and place.

Neither the advantages nor the disadvantages of any type of cropping system recommended for semiarid dryland farming in the northern Great Plains can be determined without first defining the management level of the individual who puts the system into practice. Almost any system will fail at some time under poor management and farming practices. Therefore, assuming the optimum in soil-management practices, including fertilization, seedbed preparation, tillage, and weed control, the advantages of a winter wheat-fallow cropping system are as follows:

1. Fallow insures a higher yield per harvested acre in any given year than any other cropping system.

2. Fallow, with proper tillage, insures adequate soil water near the surface to germinate seed and provide a satisfactory stand.

3. By increasing the probability of obtaining a satisfactory stand, fallow insures the production of sufficient vegetative cover and crop residue to protect the soil from wind and water erosion.

4. Fallow is effective for storing sufficient water for sustained wheat production during periods when growing-season precipitation alone is usually insufficient to obtain an economical yield.

5. Fallow helps to control weeds under all cropping systems, but most effectively if used in conjunction with crop rotations of more than one crop.

6. Fallow provides adequate time to prepare land for the succeeding crop when stubble-residue levels are excessive and the soil requires special management.

7. Fallow reduces the probability of crop damage from some diseases and insects by breaking or interrupting their life cycle and destroying their food supply. If a problem at all, most disease and insect problems affecting winter wheat would be less severe with fallow than with continuous cropping, irrespective of cropping patterns or specific tillage practices.

8. Fallow reduces the need for N fertilization on most soils.

9. Fallow more consistently produces higher quality wheat in relation to test weight and protein content than any other cropping system.

10. Fallow spreads the labor and machinery requirements over a long period of time, compared with the tillage and seedbed preparation required for annual cropping.

The disadvantages of a crop-fallow system of farming are as follows:

1. Fallow increases the susceptibility of land to wind and water erosion, particularly systems with poor crop-residue production and large blocks of land without stripcropping.

2. Some years in the northern Great Plains, fallow does not accomplish its purpose of conserving soil water during the summer of fallow; in fact, some years soil water may actually be lost, if the soil profile was completely recharged after the first overwinter period.

3. Fallow encourages the infestation of specific weeds, such as downy bromegrass, in a fixed winter wheat-fallow system.

4. Fallow contributes to the acreage of saline-seep soils, caused by deep percolation of water beyond the root zone to the depth of an impervious layer, when precipitation exceeds the amount needed to recharge the root zone and produce a crop.

5. Fallow intensifies the leaching of some plant nutrients and salts, including NO_3-N, below the root zone.

6. Fallow causes a greater loss of soil organic matter, including the plant nutrients it contains, than would be lost under other cropping systems that use fallow less frequently or not at all. This loss of soil organic matter occurs through both decomposition, which is more rapid under fallow, and soil erosion.

7. Fallow is occasionally substituted for cropping, as a result of poor-management practices, such as untimely field operations, lack of weed control, and inadequate stand establishment, in contrast with the high-level management required of cropping systems involving limited use of fallow.

Alternatives to Fallow

None of the alternatives to fallow in the northern Great Plains can succeed if the cropping sequence advocated fails to recognize the need for a flexible-cropping system. A flexible-cropping system permits the strategic use of fallow, as needed, in combination with other crops. It is important that the principles of crop rotations be carefully integrated with climatic and soil conditions as they exist at that particular time and place. On the other hand, a fixed-cropping system involving the same crop on the same land, encourages certain weed, insect, and disease problems, irrespective of fallow.

Shifting from an alternate crop-fallow system to a flexible-cropping system involving less fallow requires additional specialized equipment and better timing of all tillage, seeding, and weed-control operations. Crop-residue management and soil-fertility problems of alternative-cropping systems require intensive research and educational programs before farmers will accept the additional risks involved, even in areas or years when fallow may not be needed for soil-water conservation.

Guidelines to be used in deciding whether to fallow or recrop must be based on several factors: (1) Soil-water storage in the profile for different crops at the time of seeding, (2) water requirement of the crop to be planted, (3) probability of obtaining a stand, (4) expected growing-season precipitation, (5) crop-residue management, (6) tillage requirements to do the job, (7) previous crop and cropping history, (8) soil-fertility requirements, and (9) anticipated weed, disease, or insect problems. Before making the decision to fallow, recrop, or seed a different crop, successful operators have to determine the significance of each of these factors in relation to their overall operation and existing soil and climatic conditions.

The decision to fallow or recrop should be based first on the amount of water stored in the soil from harvest to spring. This, together with the expected growing-season rainfall, will provide an estimate of the total water that can reasonably be expected to be available for crop use. The rest of the decision-making process is so dependent on the operational efficiency and management capabilities of each individual farm operator that no fixed guidelines could possibly be established that would have across-the-board application. Although some guidelines for residue management, tillage operations, and soil fertility have been established, these guidelines necessarily have been general in application, because the interaction of these management practices with available water supplies and other management factors is extremely complex. An intensive research program using current technology is needed to evaluate these interactions and determine alternatives to fallow. Fallowing is a relatively simple practice that should not be used as a substitute for the high-level soil-management practices required under intensive-cropping systems involving less fallow.

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CHAPTER 4.—SUMMER FALLOW IN THE CENTRAL GREAT PLAINS

B. W. Greb, D. E. Smika, N. P. Woodruff, and C. J. Whitfield [1]

Introduction

The central Great Plains, as defined for this report, comprises eastern Colorado, southeastern Wyoming, and the western 75 to 80 percent of Nebraska and Kansas (fig. 4.1). The geographic boundaries of the central Great Plains include approximately 105 million acres of land. From east-to-west, the elevation increases nearly 10 feet per mile, ranging from 1,000 feet along the east boundary to 5,000 to 6,000 feet at the base of the Rocky Mountains. The elevation gradient imposes important temperature and precipitation variables on the prevailing climate, which in turn influences the type of dryland-farming system used in particular areas within the central Great Plains.

The generally level topography is drained by east-flowing major streams, such as the North Platte, South Platte, Republican, Big Sandy, Smokey Hill, and Arkansas Rivers. Numerous smaller watersheds join the major streams to form

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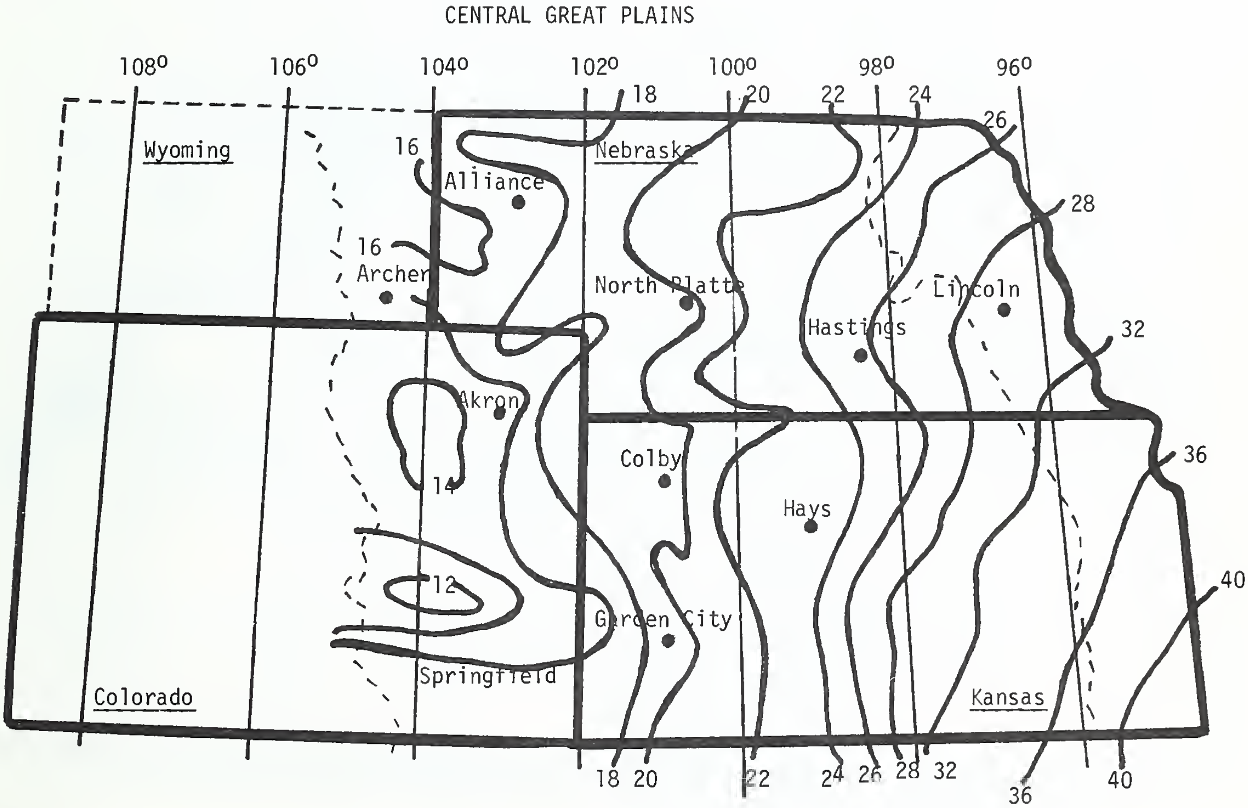


FIGURE 4.1.—Mean annual precipitation in the central Great Plains, excluding the Rocky Mountains, in inches (*28, 44, 77, 79*).

a series of islandlike plateaus of nearly level land between drainages. Most of the dryland farming is conducted on these upland plateaus.

Climate

The climate becomes progressively drier and cooler from east to west. The area between the 96° and 98° meridians is generally classified as continental subhumid, and west of the 98° meridian to the Rocky Mountains the climate is primarily semiarid (*75, 77*). The Thornthwaite (*75*) precipitation-evaporation (P-E) index across the central Great Plains shows approximately 75 percent of the central Great Plains as semiarid, 20 percent subhumid, and 5 percent arid. The mean annual precipitation for the central Great Plains (fig. 4.1) ranges from less than 12 inches in parts of eastern Colorado to over 32 inches in the Bluestem Hills of Kansas. Precipitation in all the central Great Plains is highly erratic and in individual years may be double or less than half that of long term averages. Humidity is generally low and wind velocities are high. Nearly 75 to 80 percent of the precipitation occurs during the growing season of April to October. Mean annual temperatures gradually increase from NNW to SSE and range from 44° to 46° in southeastern Wyoming to 57° at Liberal, Kans. (*77, 79*). Temperatures range from −30° to 115° in much of the area. However, temperatures exceeding 100° are usually rare in southeastern Wyoming and adjacent Colorado and western Nebraska counties.

Average annual snowfall increases in a NNW direction as the mean annual temperature decreases (fig. 4.2). The average annual snowfall gradually increases from less than 20 inches across the southeast half of Kansas to 35+ inches in extreme northwestern Nebraska and southeastern Wyoming. Snowfall is known to be a very efficient source of soil water (*10, 31, 34*), and it will be shown later that the highest average wheat yields in the western part of the central Great Plains tend to coincide with the highest average snowfall.

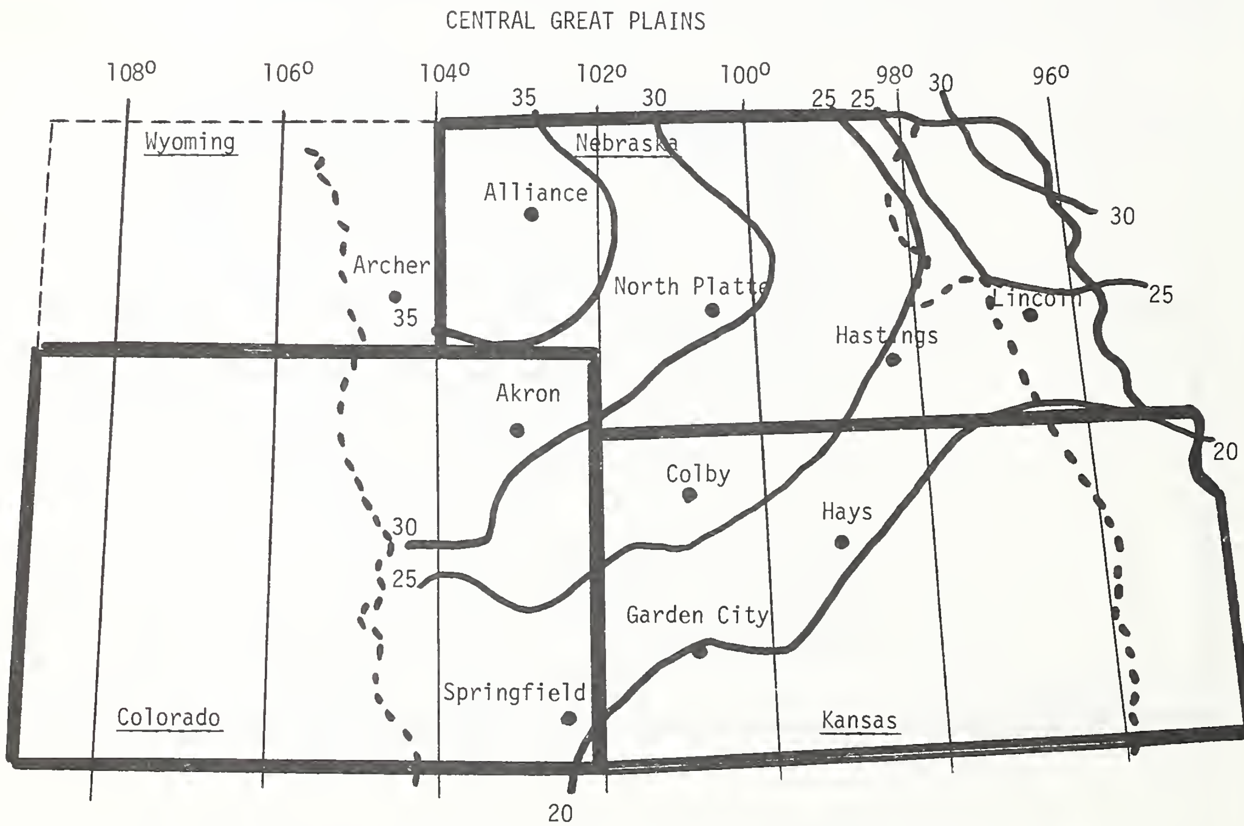


FIGURE 4.2.—Mean annual snowfall in the central Great Plains, excluding the Rocky Mountains, in inches (*7, 77*).

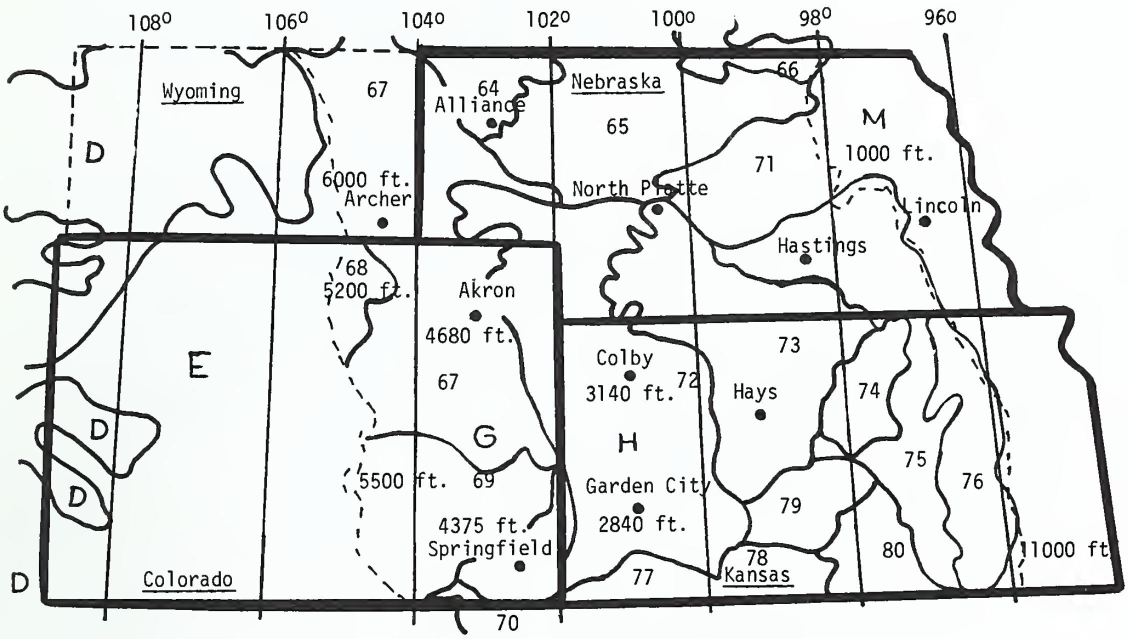
Mean annual free-water evaporation was shown in figure 1.4. Evaporation appears to be influenced by higher elevations along the western edge of the central Great Plains and also north-to-south in response to higher average temperatures east of the 102° meridian. Free-water evaporation ranges from less than 65 inches per year in southeastern Wyoming and northwestern Nebraska to over 90 inches in southwestern Kansas (fig. 1.4).

Drought is normal in all semiarid regions and particularly in the Great Plains (*54*, *57*, *80*). Hence, any and all methods of water conservation are of prime importance if successful agriculture is to be sustained (*80*). Thus, it is not surprising that one of the more widely used systems for circumventing the detrimental effects of temporary drought is that of summer fallowing.

Land and Soil Resources

Of 17 land resource areas shown in figure 4.3, the two largest include the central High Plains of eastern Colorado, southeastern Wyoming, extreme western Nebraska, the Central High Tableland of western Kansas, southwestern Nebraska, and the extreme northeastern corner of Colorado (*5*). Both of these land resource areas are largely west of the 100° meridian and include the most of the fallow area of the central Great Plains. The Rolling Plains and Breaks of south-central Nebraska and north-central Kansas, the Central Loess Plains, Nebraska Loess

CENTRAL GREAT PLAINS



LAND RESOURCE REGIONS AND MAJOR LAND RESOURCE AREAS

D. Western Range and Irrigated Region
E. Rocky Mountain Range and Forest Region
G. Western Great Plains Range and Irrigated Region
  64. Mixed Sandy and Silty Tableland
  65. Nebraska Sand Hills
  66. Dakota-Nebraska Eroded Tableland
  67. Central High Plains
  68. Irrigated Upper Platte River Valley
  69. Upper Arkansas Valley Rolling Plains
  70. Pecos-Canadian Plains and Valleys
H. Central Great Plains Winter Wheat and Range Region
  71. Central Nebraska Loess Hills
  72. Central High Tableland
  73. Rolling Plains and Breaks
  74. Central Kansas Sandstone Hills
  75. Central Loess Plains
  76. Bluestem Hills
  77. Southern High Plains
  78. Central Rolling Red Plains
  79. Great Bend Sand Plains
  80. Central Rolling Red Prairies
M. Central Feed Grains and Livestock Region

FIGURE 4.3.—Land resource regions and major land resource areas (and locations referred to in text, including altitudes of some locations) of the central Great Plains and adjacent Rocky Mountains (*5*).

Hills, Great Bend Sandy Plains, and the Bluestem Hills are sizable land resource areas that lie primarily east of the 100° meridian (*5*).

As shown in figure 4.4, the central Great Plains, excluding the Rocky Mountain region, includes five Great Soil Groups, eight soil orders, and 24 soil suborders (*78*). Of the five Great Soil Groups represented, the Mollisols include roughly 75 percent of the land area and nearly 97 percent of the cultivated acreage. Under the former soil system of classification, the Mollisols would range from Light brown > Brown > Dark Brown > Chestnut > near Chernozem in a west to east direction. The largest acreage of fallow wheat is on soil suborders M9-4 and M9-19 (fig. 4.4).

The sandy soils are residual in origin, and the loam, silt loam, and clay loam soils are loess deposits (*21*, *44*). With few exceptions both the sandy and medium-textured soils are deep and do not contain inhibiting rock layers except at considerable depth. Nearly all the soils in the central Great Plains are calcareous, with the "B" horizon lime layer varying in depth with texture and effective precipitation. Thus, shallow "A" horizon profile soils are found in drier zones or on steep sloping topography in wetter zones. Moderately deep soils are generally found on nearly level land, and deep soils such as Scott, Goshen, Keith, and Holdredge soils are found in swales where water is more plentiful in low precipitation areas or on level land in higher precipitation areas.

Cultivated sandy soils average less than 1.0 percent organic matter, and are low in total N (0.05 percent) and available phosphorus [2] (*35*, *36*, *60*). The noneroded dark-brown Mollisols of medium texture are fertile, generally averaging 1.9 to 2.3 percent organic matter, 0.10 to 0.15 percent total N, and over 40 pounds/acre available P in the surface 6 inches of soil. The brown and light-brown Mollisols usually average 1.4 to 1.8 percent organic matter, about 0.08 percent total N, and from 15 to 30 lbs/acre available P in the surface 6 inches of soil. However, considering the shallow "A" horizon of the brown and light-brown Mollisols, any removal of top soil by erosion seriously threatens these soils with serious nitrogen and phosphorus deficiencies [3] (*8*, *11*, *60*).

The medium-textured soils of the central Great Plains possess reasonably good water intake rates—1 inch per hour for the first hour and 0.2 to 0.4 inch per hour thereafter.[3] These soils have a water-holding capacity of 22 to 25 percent in the "A" and "B" horizons and 18 to 22 percent in the silty parent material of the "C" horizon. A typical medium-textured soil (Rago, Keith, or Holdredge) can hold 12 to 13 inches of available soil water in a 6-foot profile (*34*, *70*).

Crops and Cropping Practices

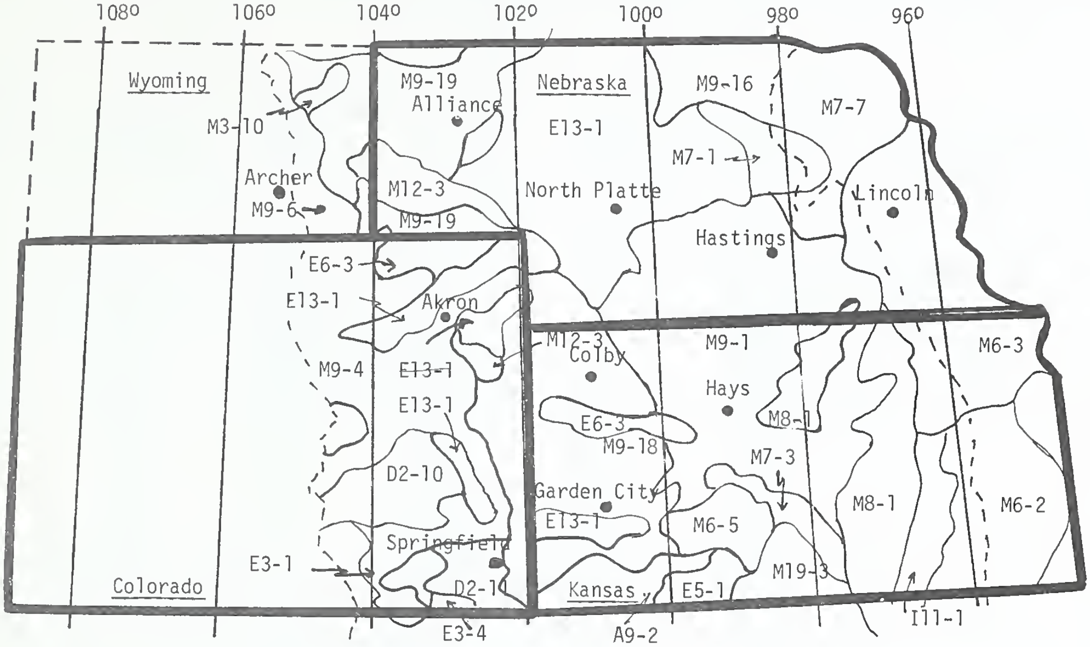
Data regarding the expansion of dryland acres cultivated, acres planted to wheat, acres fallowed, and acres planted to corn and sorghum in the central Great Plains are given in table 4.1. Development of dryland cultivation acreage had been nearly completed in Kansas and Nebraska by 1920; whereas, virgin sod was still being plowed in eastern Colorado as late as 1952. About 4 million acres of land was broken in Colorado between 1946 and 1950. Most of these new acres were in the east-central and southeastern counties. About 54 million acres of the central Great Plains were under cultivation by 1955. Since 1957 the dryland acreage has decreased about 10 million acres, because of development of pump irrigation and the retirement of land in response to government acreage programs.

Before 1920, corn occupied more acreage than wheat over much of the central Great Plains. Beginning in 1930, the corn acreage has gradually dropped from 18.0 million acres to only 4.1 million acres by 1968. Expansion of fallow and sorghum have largely replaced 75 to 80 percent of the acreage formerly in corn. Fallow acreage increased dramatically in Kansas during the 1930's and in both Nebraska and Kansas after 1960. Sorghum acreage expanded most during the 1950's. Wheat acreage was highest from 1950 to 1952. However, the acreage has not materially changed since 1932 to the present (1972). Although not shown in table 4.1, the present dryland cultivated acreage in southeastern Wyoming includes approximately 350,000

[2] Shawcroft, R. W., and B. W. Greb. annual research report. U.S. Central Great Plains Field Station, Agr. Res. Serv., U.S. Dept. Agr., Akron, Colo. 1963.

[3] Greb, B. W. annual research reports. U.S. Central Great Plains Field Station, Agr. Res. Serv., U.S. Dept. Agr., Akron, Colo. 1956–70.

CENTRAL GREAT PLAINS



Soils in the Central Great Plains

Great Soil Group	Soil Order	Symbol	Soil Suborders
Alfisols (Red-Brown)	Ustalfs	A9-2	Haplustalfs plus Calciustolls and Argiustolls
Aridisols (Sierozen to Light Borwn	Argids	D2-10	Haplargids plus Torriorthents and Argiustolls
		D2-11	Haplargids plus Torriorthents, Argiustolls, and Torripsamments
Entisols (Brown, Sandy or shallow)	Orthents	E3-1	Torriorthents plus Haplargids and Torrifluvents
		E3-4	Torriorthents plus Torriorthents (shallow), Haplargids and rough stony land
		E5-1	Ustorthents plus Argiustolls and Argiudolls
		E6-3	Ustorthents (shallow) plus Ustorthents
	Psamments	E13-1	Ustipamments
Inceptisols	Ochrepts	I11-1	Ustochrepts (shallow)
Mollisols (Brown to Chestnut)	Borolls	M3-10	Argiborolls plus Ustorthents and Boralfs
	Udolls	M6-2	Arguidolls plus Albaqualfs and Paleudolls
		M6-3	Argiudolls plus Argiaquolls
		M7-1	Hapludolls
		M7-3	Hapludolls plus Argiudolls
		M7-7	Hapludolls plus Ustorthents
		M8-1	Hapludolls (shallow) plus Argiustolls and Argiudolls
	Ustolls	M9-1	Argiustolls
		M9-4	Argiustolls plus Haplargids, Ustorthents, and Paleustolls
		M9-6	Argiustolls plus Haplustolls
		M9-13	Argiustolls plus Paleustolls
		M9-16	Argiustolls plus Ustipsamments
		M9-18	Argiustolls plus Ustorthents
		M9-19	Argiustolls plus Ustorthents (shallow)
		M12-3	Haplustolls plus Argiustolls plus Ustorthents

FIGURE 4.4—Distribution of soils in the central Great Plains, excluding the Rocky Mountains (*78*).

TABLE 4.1.—*Expansion of dryland acres cultivated, fallowed, and planted to principal crops in Colorado, Kansas, and Nebraska (17, 47, 59)*

State and year	Acreage, 1,000 acres					Percent of acres in fallow
	Cultivated	Planted to wheat	Fallowed	Planted to corn	Planted to sorghum	
Colorado:						
1890	300	80	----	60	----	
1900	300	120	----	95	----	
1910	800	400	40	200	----	
1920	3,300	1,495	500	900	400	5
1930	5,045	1,915	750	1,350	295	15
1935	5,200	1,390	800	1,200	400	15
1940	5,400	1,050	875	1,030	795	16
1945	7,000	1,600	1,350	670	1,000	19
1950	8,475	2,950	2,580	380	645	30
1952	9,450	3,700	3,600	255	640	38
1955	9,000	3,000	3,060	195	1,700	34
1960	8,405	2,600	2,685	80	665	32
1965	7,750	2,895	3,000	25	765	39
1968	8,000	3,105	3,300	25	655	41
Kansas:						
1880	8,870	156	----	560	----	
1890	15,930	2,160	----	3,805	----	
1900	23,210	4,290	----	7,470	----	
1910	33,395	6,985	----	8,950	----	
1920	22,775	10,560	[1] 595	5,330	----	3
1930	24,345	13,685	[1] 1,260	7,150	1,570	5
1935	21,005	13,455	[1] 3,780	5,600	2,830	18
1940	20,330	12,360	[1] 4,845	3,050	4,110	19
1945	22,910	14,150	[1] 3,385	8,060	2,875	15
1950	21,615	13,805	[2] 3,995	2,610	3,085	18
1955	24,740	10,800	[2] 4,525	1,800	5,455	18
1960	21,510	10,725	[2] 5,050	1,780	4,980	23
1965	19,285	10,640	[2] 6,135	1,730	5,065	32
1968	19,340	11,970	[2] 5,675	1,450	4,470	29
Nebraska:						
1870	2,075	170	----	155	----	
1890	10,975	1,520	----	5,525	----	
1900	14,955	2,750	----	7,350	----	
1910	19,310	3,890	----	7,425	----	
1920	18,935	3,885	----	7,660	----	
1930	21,500	4,075	945	9,565	130	4
1935	22,000	3,885	1,050	7,450	2,990	5
1941	20,315	3,275	1,460	6,820	1,395	7
1946	20,210	4,035	1,290	8,060	365	6
1950	21,445	4,345	1,675	7,020	475	8
1955	20,065	3,485	2,150	6,715	1,300	11
1960	18,960	3,305	2,220	6,885	2,030	12
1965	18,155	3,260	3,300	3,875	2,690	18
1968	16,445	3,325	3,390	2,610	1,640	21

[1] Fallow and idle land.
[2] Cultivated fallow.

acres of fallow, 200,000 acres planted to winter wheat, and 100,000 acres to other small grains. As of 1970, 43.8 million acres were being cultivated in the central Great Plains (40 percent of all land area), with 18.4 million acres planted to wheat, 12.7 million fallowed, 4.1 million planted to corn, and 6.8 million planted to sorghum.

As the precipitation, elevation, and mean temperature patterns change across the central Great Plains, the principal land use also changes (fig. 4.5 and table 4.2). The land area between the 96° and 98° meridians is devoted primarily to the continuous cropping of wheat, corn, and grain sorghums and some small grains. The "fallow transition" (where fallow is often practiced but is not always necessary) area, principally between the 98° and 100° meridians, was formerly devoted to continuous cropping until the advent of the fallow-wheat-sorghum rotation. This rotation, with an estimated 3.1 million acres being fallowed, is believed to occupy about 45 percent of the cultivated acres of the fallow transition zone. A mixture of continuous wheat, corn, and/or sorghum occupies another 45 percent of the acreage. Miscellaneous crops occupy the remaining 10 percent (*47*).

West of the 100° meridian at the 2,500 to 5,500-foot elevations, the climate is distinctly semiarid. However, temperature and rainfall variations within this area are of sufficient magnitude that three climatic and two land-use subdivisions are recog-

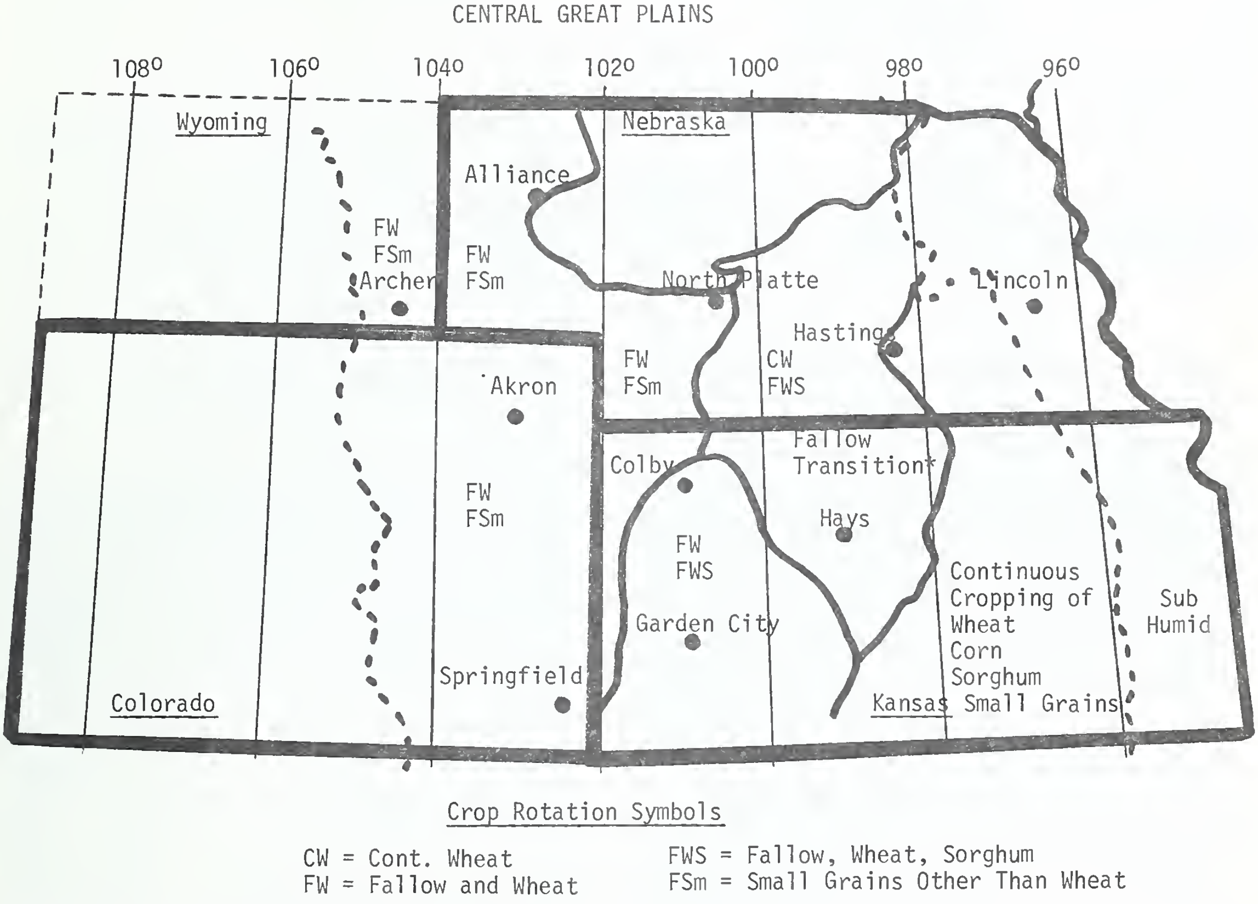


FIGURE 4.5.—Use of cultivated land in the central Great Plains. (Fallow transition includes area where fallow is often practiced but is not always necessary.)

TABLE 4.2.—*Estimated distribution, and rotational use, in the central Great Plains, 1970*

Geographic location	Average precipitation	Type crop rotation [1]	fallow
	Inches		*Million acres*
South-central Nebraska and north-central Kansas (Fallow transition zone, see fig. 4.5)	22–27	CW	----------
		FWS	3.1
Northeastern Colorado, western Nebraska, and southeastern Wyoming	15–22	FW	3.4
		FWSm	.9
Western Kansas	16–22	FW	2.3
		FWS	2.0
Southeastern Colorado and fringe of southwestern Kansas	11–15	FW	1.0
Total			12.7

[1] CW, Continuous wheat; FW, fallow and wheat; FWS, fallow-wheat-sorghum; FWSm, fallow-wheat-millet or other spring small grains (barley. rye, etc.).

nized. The largest area, which includes western Nebraska, southeastern Wyoming, and most of eastern Colorado, is considered cool semiarid [4] and is largely devoted to a fallow-wheat rotation. Southeastern Colorado and the extreme southwest fringe of Kansas lie in a dry, warm semiarid [4] (near desert) environment. This area is also a fallow-wheat area, but has an extensive acreage of sorghum planted when wheat often fails during the dormant season. Most of western Kansas, occupying 24 counties, is moderately semiarid [5] and includes acreages of both fallow-wheat and fallow-wheat-sorghum (see fig. 4.6).

Since 1938, wheat grown continuously after wheat or after row crops represents a minority of acreage west of the 100° meridian (*17, 47, 59*). Zook and Weakley (*89*) show that during 1931–41 an average of 91 to 92 percent of all wheat in western and southwestern Nebraska was planted on fallowed land. In western Kansas, an average of 85 to 90 percent of wheat was planted on fallowed land during 1939–58 in the northwestern counties and 70 to 80 percent in the southwestern counties.[5] Although exact figures are lacking for Colorado, statistics show 98 percent as many acres fallowed as were planted to dryland wheat (*17*). Land devoted to fallow in this area west of the 100° meridian has leveled off to about 9.6 million acres.

[4] Authors define cool semiarid as less than 22 inches precipitation and less than 53° F. mean annual temperature; dry, warm semiarid as less than 17 inches annual precipitation with mean annual temperature greater than 53°; and moderate semiarid as 17 to 23 inches precipitation and mean annual temperatures greater than 53°.

[5] GREB, B. W. CLIMATE AND CULTURAL PRACTICES AFFECTING WINTER WHEAT PRODUCTION IN 58 COUNTIES OF THE WESTERN SECTION OF THE CENTRAL GREAT PLAINS. Unpublished Rpt. 1960.

Water Conservation

Storage Efficiency

At any given location within the fallow area of the central Great Plains, the climate fluctuates from arid to subhumid within a given year or over a series of years. Research and the agricultural industry for more than 60 years have explored a wide variety of crop and management techniques to more nearly stabilize economic production under these highly fluctuating climatic conditions. However, the immediate discussion concerns only the relation of fallow to increasing the storage efficiency of soil water.

The use of fallow as a practice for improving and stabilizing crop production has been tested since 1910 to 1915 at seven field stations in the central Great Plains. These stations are located at Alliance and North Platte, Nebr.; Archer, Wyo.; Akron, Colo.; and Colby, Garden City, and Ft. Hays, Kans. In earlier years, methods of fallow experiments were conducted tc explore the use of various types of implements, dates of primary tillage, and frequency of tillage. In come cases, the use of fallow for two or more consecutive years was also tested (*49, 50*). Generally, there was a natural evolution of fallow techniques in response to periodic upgrading of mechanisms for increased power, speed, depth of tillage, and in the design of tillage implements for improved weed control and soil-water intake.

Table 4.3 shows the estimated changes in water-storage efficiency resulting from specific evolutionary changes at three of the experimental locations in the central Great Plains. Although the average

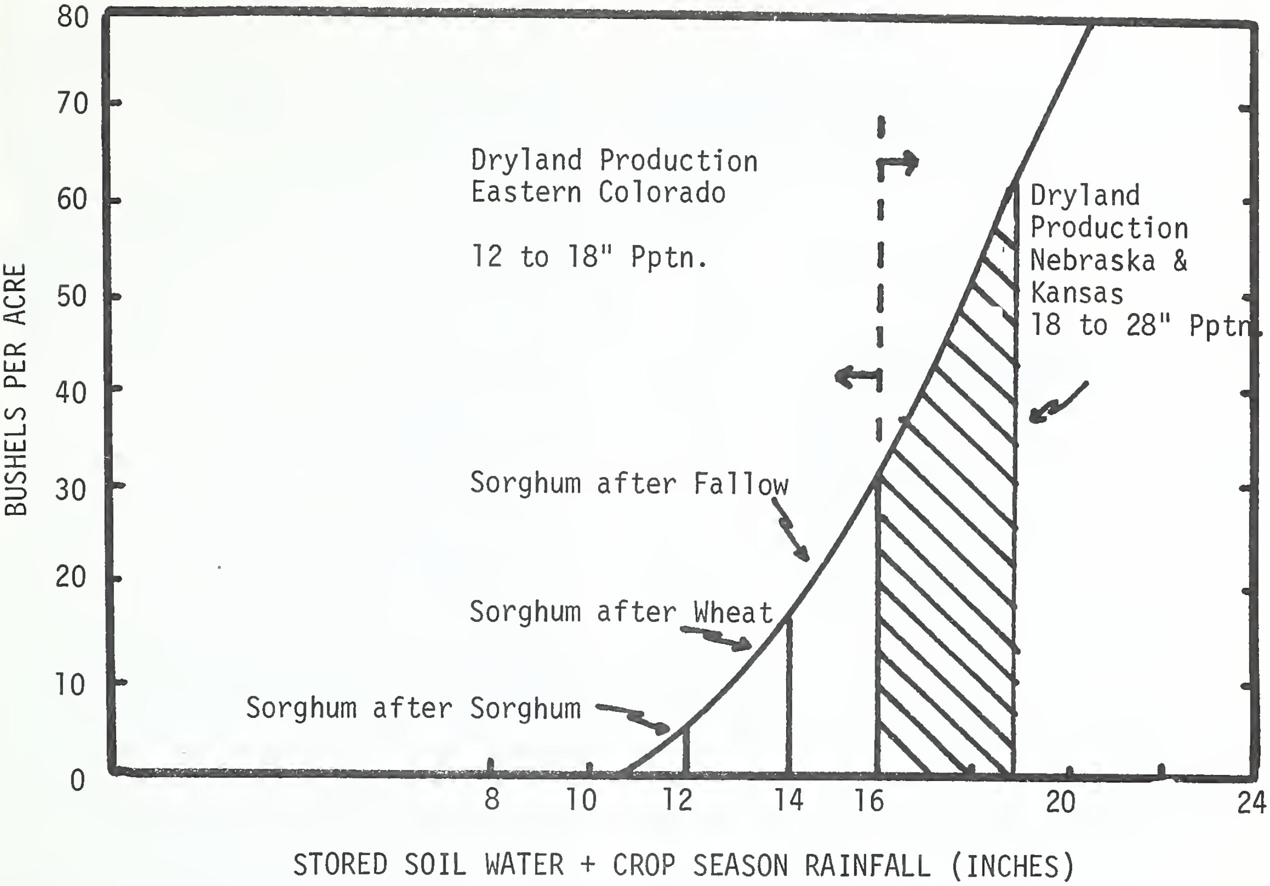


FIGURE 4.6.—Grain sorghum yield expectancy in relation to available water in the central Great Plains (*8, 48, 61, 67*).

precipitation during the 14-month fallow season varied from 20.0 inches at Akron, Colo., to 23.4 inches at Colby, Kans., and 24.4 inches at North Platte, Nebr., the storage efficiencies were of similar magnitude for each evolutionary stage at all three locations. The net soil-water gain during 14 months of fallow has consistently exceeded 6.0 inches for all three locations since 1957.

Thus, new fallow techniques utilizing better stubble-mulch and weed-control management as pioneered by research, in combination with improved mechanization, has increased storage efficiency from about 17 to 20 percent in the earlier years of 1910–30 to about 35 to 41 percent on experimental plots by 1970 [6,7] (*13, 33, 34, 39, 40, 49, 69, 71, 89*). Storage efficiencies were significantly improved by 3 to 9 percent with the use of increased rates of straw mulch (1,500 to 6,000 lbs./acre) at Akron, Colo., and North Platte, Nebr., as compared with lesser rates of mulch (*33, 34*). Storage efficiencies at Akron, Colo., in 1968 were shown to vary from 25 to 38 percent dependent upon the texture and color of surface soil (*11*). Clay at or near the soil surface was much more inhibiting to fallow storage of water than was a continuous cropped loam or silt loam soil profile (*11*). In 3 years (1968–70) of testing at Akron, fall weed control with Atrazine-Amitrol herbicide treatments averaged 35 percent storage efficiency for a relatively dry 3-year period.[8] Fall weed control has been even more effective at North Platte (*71*) than at Akron, Colo.

Thus, changes that were most effective in improving storage efficiencies included: (1) Maintenance of

[6] See footnote 3, p. 54.

[7] COLBY BRANCH EXPERIMENT STATION. ANNUAL REPORTS. Kans. Agr. Expt. Sta. Colby, Kans. 1950–63.

[8] GREB, B. W. ANNUAL RESEARCH REPORTS. U.S. Central Great Plains Field Station. Agr. Res. Serv., U.S. Dept. Agr. Akron, Colo. 1967–70.

TABLE 4.3.—*Estimated changes in storage efficiency on experimental plots at 3 semiarid Central Great Plains locations based on research and records (8, 12, 33, 34, 39, 40, 49, 71, 69, 89)*

Approximate years	Stage of fallow evolution	Soil water storage during fallow						Area avg.
		Akron, Colo.		North Platte, Nebr.		Colby, Kansas		
		Inches	*Percent Eff.*	*Inches*	*Percent Eff.*	*Inches*	*Percent Eff.*	*Percent Eff.*
1911–30	Shallow operating plows and harrows.	4.0	20	5.2	21	3.9	17	19
1931–46	Introduction of small oneway disk.	4.8	24	5.9	24	5.1	22	23
1946–58	Introduction of rod weeder	5.5	27	6.7	27	5.8	25	26
1959–66	Modern stubble mulch with large sweeps and rod weeder with tongs.	6.3	31	8.4	34	[3] 7.8	[3] 33	32
1967–70	Fall weed control in combination with stubble mulch.	7.0	35	[4] 10.0	41	Not used	Not used	[5] 38
Assuming average precipitation during 14 months fallow.		20.0	----------	24.4	----------	23.4	----------	22.6

[1] Colby Branch Experiment Station. Annual reports. Kans. Agr. Expt. Sta. Colby, Kans. 1950–63.
[2] Greb, B. W. Annual research reports. U.S. Central Great Plains Field Station. Agr. Res. Serv. U.S. Dept. Agr. Akron, Colo. 1956–70.
[3] Study completed with 1963 harvest.
[4] From 1963 to 1970.
[5] Two-location average.

surface straw mulches and rough soil surfaces for better water intake; (2) improved timing, depth, and speed of tillage for weed control; and (3) reduction of soil-water evaporation losses [9] (*4, 33, 34, 71*). In addition, snow-conservation techniques as developed at Akron, Colo., and Sidney, Mont., may conceivably further increase soil-water storage efficiency in those areas where annual snowfall expectation exceeds 25 inches (*10, 31*).

The storage-efficiency values given here for Akron, Colby, and North Platte are higher than the values of 13 to 26 percent found in the literature for the central Great Plains (*49, 56, 89*). These lower values were obtained from older systems of fallow and did not include the recent progress made in this area of research. For example, on early fallow plots at Colby, Kans. (*49*), there was no fall weed control and therefore an average 6.24 inches of late-summer rainfall increased soil-water storage by only 0.07 inch. Losses of soil water to weeds and volunteer wheat were particularly heavy when the soil held considerable water at harvesttime (*49*).

Mathews and Army (*56*) showed only a 13.0 percent storage efficiency at Akron, Colo., during an 8-year test period. This test was before 1920 and hardly represented the modern fallow systems used today. The lowest storage efficiencies recorded at this location since 1955 occurred in 1969, with 17 percent for conventional spring-tillage fallow and 10 percent for fall one-way disking.[10] That same year in the same experiment several fall weed control treatments showed 29 to 32 percent storage efficiency.[10]

Mathews and Army (*56*) also cited North Platte, Nebr. with a 22.0 percent storage efficiency for an early 17-year period; whereas, Zook and Weakley (*89*) reported a 26.5 percent storage efficiency for this location with 24 years of data. Data supplied since 1959 have shown that storage efficiencies at North Platte could range from 25 to 42 percent—dependent upon the length of the fallow period in a

[9] See footnote 3, p. 54.

[10] See footnote 8, p. 59.

given crop-rotation system, amount and manner in which straw mulches are used, and the quality of weed control during fallow (*33*, *34*, *71*).

Fenster and McCalla (*26*) reported storage efficiencies of 20.0, 16.4, and 17.2 percent for subtill (stubble mulch), one-way disk, and plow systems of fallow, respectively, from 1959 to 1965 in western Nebraska. However, these results only included sampling to a soil depth of 48 inches; whereas, significant soil-water penetration in fallow frequently extends to 72 inches or deeper (*24*, *71*). This has been particularly true under mulch fallow (*34*). Thus, with deeper sampling, a higher storage efficiency might have been recorded by Fenster and McCalla.

One of the problems of reviewing literature pertaining to water storage during fallow involves the nonuniformity of length of fallow (spring versus winter wheat versus fallow-wheat-sorghum) rotation plots, method of sampling (hand versus machine), depth of soil (shallow soil factor), depth of sampling, and the systematic bias of many field plots in relation to surrounding terrain and climate. In the past, hand sampling with king tubes did not encourage an abundance of sampling in proper number or depth.

Nevertheless, storage efficiencies can be expected to vary considerably within the central Great Plains in response to climatic factors such as temperatures and precipitation patterns. The northern cooler areas receive more snowfall (see fig. 4.3) and therefore receive water in a more efficient form than the warmer southern areas (*31*, *34*). Data at Akron, North Platte, and Colby show that soil-water storage from snowfall usually exceeds 50 percent and often approaches 100 percent; whereas, during the summer months there is little if any net soil-water storage gain from fallowing (*31*, *34*, *49*). It is also likely that the higher free-water evaporation rates in the warmer southern part of the central Great Plains (see fig. 1.4) decreases storage efficiencies over the 14-month fallow season. In addition this area has a much longer growing season for consumption of soil water by weeds and volunteer wheat.

In summary, storage efficiencies are known to be affected by the following factors: (a) Length of fallow, (b) climatic conditions during the fallow season (and before in some cases), (c) amount and management of mulches, (d) quality of weed control, (e) soil texture, (f) soil reflectance, (g) soil depth to inhibiting layers, and (h) tillage implements used to modify the soil surface. These factors have been recognized and used as a technical base for improvement where feasible. This improvement of fallow has had an impact on the water-use efficiency as will be shown under "Crop Yields."

Methods of Tillage

The objectives of tilling fallow in a winter wheat-fallow system are that: (a) The fallow land be weed free from date of harvest to date of planting 14 months later, (b) the wheat stubble remain upright during the winter to catch snow, (c) a straw mulch of 1,000 to 1,500 pounds/acre be present at seeding time, and (d) large soil clods be maintained during fallow and after fall seeding. These objectives maximize soil-water storage and soil-nitrate supplies, assure better seed germination, and reduce wind-erosion potential to near zero (*4*, *22*, *24*, *45*, *49*, *65*, *69*).

The number of tillage operations used by commercial operators for fallow varies greatly with climate, weed-growth conditions, and management habits. Seedings have been made on land receiving two to 12 fallow operations. Most operators now till four to six times per season.

Numerous tillage implements have been used to conserve soil water during fallow. Some of the better known implements are:

Deep-tillage types	*Shallow-tillage types*
Lister	Duckfoot cultivator, small V blade
Lister dammer	Sweep, V blades, 3 to 7 ft.
Chisel	Sweep, bar blades, straight
Chisel dammer	Rod weeder (rotary bar), bare
Plow, moldboard	Rod weeder, with tong attachments
Plow, large disk	Skew treader
Subsoiler, (heavy shank chisel)	Rotary hoe
	Disk, one-way
Vibrator chisel	Disk, tandem
	Harrows, spring-tooth, spike-tooth

No attempt will be made to explore the advantages and disadvantages of each implement. Additional information regarding dryland tillage implements can be obtained from publications (*2*, *18*, *24*, *45*, *55*, *65*, *82*, *83*, *84*, *85*).

In general, deep tillage, if used, is the first or primary tillage operation on wheat stubble. There has been little experimental evidence that deep tillage conserves more soil water or increases wheat yields on long term experiments than does shallower tillage (*43*). Special reasons for using deep tillage may include: (a) Breakage of shallow morphological clay horizons [11] or tillage pans created by successive shallow tillage; (b) burial of undesirable grassy weed species such as downybrome (*26*, *81*); (c) emergency tillage for wind-erosion control (*55*); and (d) throwing up large clods to conserve snowmelt (*53*). Shallow tillage: (a) Is less expensive per unit acre and per unit bushel produced; (b) makes it easier to obtain wider coverage; (c) may be used to preserve vegetative residues on the soil surface; and (d) is a requirement for seedbed preparation. Chemical fallow offers a distinct possibility as a replacement for one or more tillage operations in a fallow system (*9*, *25*, *71*).

A typical time sequence of field operations in the wheat-fallow system in the western section of central Great Plains follows:

Time	*Field operations and conditions*
Early July	Harvest wheat
August to early April	Undisturbed wheat stubble, fall weed control often desirable but usually needed [1] (*71*)
April 20 to May 7	Initial tillage of fallow
May through August	Cultivate fallow
September 7 to 27	Plant wheat

[1] See footnote 8, p. 59.

Some operators attempt to economize by using "one tool" fallow year after year. This practice can be detrimental, for example, continued operation with a disk implement can destroy soil clods and surface residues (*84*) thus increasing susceptibility to erosion. On the other hand, repeated use of subtillage equipment may encourage certain weed species such as downybrome (*26*). In most cases, a variety of implements is desirable to meet changing climatic, soil, residue, and weed conditions.

A fallow system that has been highly successful at North Platte, Nebr., and Akron, Colo., for the conditions existing in the central Great Plains is as follows:

Time	*Field operation*
July 25 to Aug. 5	Sweep 4 inches deep to destroy fall weeds in new wheat stubble.
Sept. 1 to 10	Cross sweep 4 inches deep to kill volunteer wheat if needed.
April 20 to May 10	One-way disk if heavy volunteer or excessive straw is present, otherwise sweep 4 inches deep.
June 15 to 25	Sweep 3 inches deep.
July 15 to 25	Rod weed 3 inches deep with tongs attached.
Aug. 20 to Sept. 1	Cross rod weed 3 inches deep with tongs attached.
Sept. 10 to Sept. 20	Drill wheat with deep-furrow hoe drill, 10- to 14-inch row widths with furrow openers 4 to 5 inches deep in soil.

The sweeps used at Akron and North Platte are 6-foot V blades with 45° pitch and are pulled quite rapidly to increase turbulence of soil sliding over the blades.

The importance of weed control in fallow can hardly be over emphasized [12] (*9*, *12*, *39*, *54*, *71*). Briggs and Shantz (*15*) and Shantz and Piemeisel (*67*) listed 10 common broadleaf weeds having an average water requirement of 515 ± 23 pounds of water per pound of dry matter produced. This value for weeds is nearly identical to the 507 ± 6 pounds given for winter wheat (*67*). Thus, every pound of weed tissue grown during fallow subtracts 1 pound of wheat tissue. One acre-inch of water can grow 460 pounds of weed tissue or 460 pounds of wheat. Assuming a 1:1 straw to grain ratio growth input near the heading stage, then about 230 pounds, or about 4 bushels/acre, of grain is lost for each acre-inch of water used by weeds.

In the central Great Plains, uncontrolled weed growth often produces 1,000 to 2,400 pounds/acre dry matter in wheat stubble between the mid-July harvest and the first freeze in late September.[13] This level of weed production can consume over 3 inches of available soil water and 30 pounds/acre available nitrogen. At Akron, Colo., eight methods of weed control by various tillage and chemicals

[11] Greb, B. W. DEEP PLOWING A SHALLOW CLAY LAYER TO INCREASE SOIL WATER STORAGE AND CROP YIELD. Colo. Expt. Sta. Prog. Rpt. 70–23. 1970.

[12] See footnote 8, p. 59.

over a 3-year period showed conclusively that a significant part of the water and nitrogen being wasted by fall weed growth could be saved and utilized by the succeeding wheat crop 23 months later in a fallow-wheat system. The best control of fall weed growth was achieved by either (a) sweep tillage at 1 and 5 weeks after harvest or (b) the application of Atrazine plus Amitrol herbicides ($\frac{3}{4}$ lb./acre active each) 1 week after harvest. These two treatments reduced potential weed growth by 70 to 80 percent and thereby increased storage of soil water in fallow by 1.0 to 2.0 inches and soil-nitrate nitrogen by 20 to 30 pounds/acre. Consequently, yields of winter wheat were increased 5 to 14 bushels grain/acre, straw yields by 500 to 1,000 pounds/acre, and the protein content of wheat by 0.5 to 1.0 percent.[13] Similar results have been reported in both fallow-wheat and fallow-wheat-sorghum rotations by Smika and Wicks at North Platte (*71*).

The introduction of the rod weeder (with tongs attached) has greatly improved late-season fallow operations in the central Great Plains since the early 1950's. This implement effectively kills weeds, maintains excellent clods and straw mulch, and sets a compressed moist soil zone at 2 to 4 inches soil depth. With the use of this implement, it has been possible at Akron, Colo., and North Platte, Nebr., to achieve successful germination of wheat even when no rain was received during the last 4 to 5 weeks of fallow.

Various aspects of stubble-mulch tillage under semiarid conditions has been reported by a number of workers (*2, 18, 19, 20, 23, 24, 25, 33, 34, 40, 51, 70, 82, 83, 84, 85, 88*). In general, stubble mulching greatly reduces the wind-erosion hazard and increases stored soil water during fallow. Soil temperatures are generally lower in the spring under straw mulch than under bare soil, but are usually higher in the fall. Increasing soil-water storage by mulching has not always resulted in yield increases. Yield trends resulting from mulches have tended to be positive under warm, dry spring growing conditions and slightly negative under cold, wet conditions (*34, 88*). Nevertheless, improved machinery and general benefits from mulching have been sufficiently favorable that stubble mulching is now used on 50 to 55 percent of all fallow acres in the central Great Plains.[14]

The maintenance of mulches by various implements has been studied by Anderson (*2*), Duley and Fenster (*19*), Fenster (*24*), and Woodruff and coworkers (*82, 83, 84, 85*). Subtillage with sweeps, rod weeders, and other subsurface operating implements were shown to preserve mulches much better than disk-type implements.

Erosion

Wind

Wind erosion is a problem of considerable significance to agriculture in the central Great Plains. During the decade 1961–70 the Soil Conservation Service Wind Erosion Reports have indicated an average annual number of acres damaged of 405,900, 201,900, 144,200, and 89,200 in Colorado, Kansas, Nebraska, and Wyoming, respectively. Maximum number of acres damaged in any one year was 2,065,000 in Colorado during 1964, and minimum damage was 7,900 acres in Kansas in 1969.

As shown on figure 4.7, the wind-erosion potential in the central Great Plains is greatly magnified by the increasing severity of climate (see figs. 1.4, 4.1, and 4.2). Thus, the erosion potential increases several times from Hastings, Nebr., southwestward to Springfield, Colo. Even at Akron, Colo., the wind-erosion potential is roughly two to three times less severe than in nearby southeastern Colorado and southwestern Kansas.

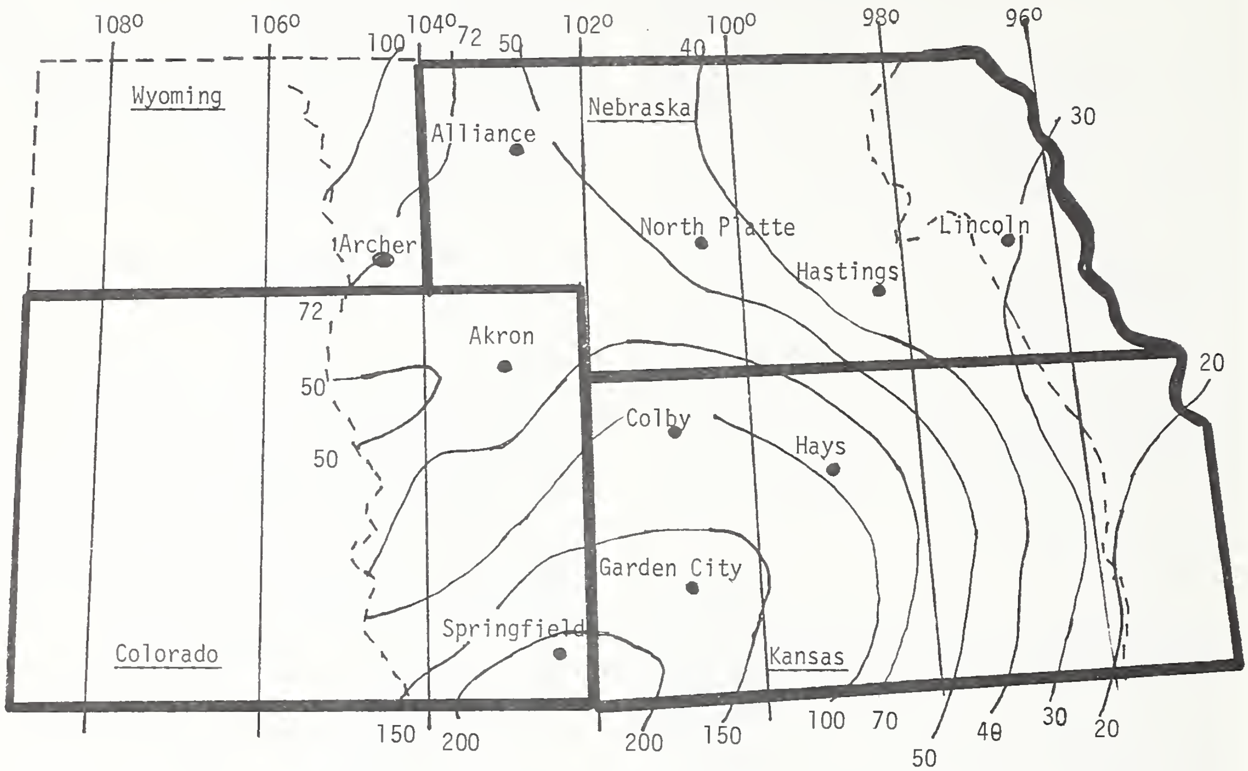
Soil erosion by wind is determined by the wind velocity, surface soil water, soil cloddiness, surface roughness, field length along the direction of the wind, and vegetative cover on the field (*86*). When the wind is strong, the soil dry and pulverized, the field long and smooth, and vegetative cover is absent or insufficient, then the soil will blow irrespective of whether it is summer fallowed or continuously cropped.

The literature indicates that summer fallow has developed a reputation as a strong contributor to the occurrence of wind erosion, especially if it is not handled properly (*22, 26, 41, 45, 49, 55, 76*).

[13] See footnote 8, p. 59.

[14] U.S. Agricultural Stabilization and Conservation Service. Agricultural conservation program. U.S. Agr. Stabilization and Conserv. Serv. Ann. Sums. 1961–67.

CENTRAL GREAT PLAINS



Relative Erosion Hazard

Very Low	0-17	High	72-150
Low	18-35	Very High	150
Intermediate	36-71		

FIGURE 4.7.—Relative wind erosion hazard in the central Great Plains excluding the Rocky Mountains (*68*).

Apparently these opinions have been formed more from observations than from research, because actual data are scarce for measurements of the erosiveness of fallow land as compared with continuously cropped land. Zingg (*87*) did report that wind erosion from certain kinds of poor fallow could be four times greater than from continuous wheat; but this same study also showed that the relative erodibility of continuous wheat was 10 times greater than from good stubble-mulch fallow accomplished with modern sweeps and rod weeders. One conclusion is that fallow has been a significant contributor to wind erosion mostly because of the way it was tilled; however, this should no longer be true. Many types of subsurface tillers, drills, mulches, and planters capable of planting in straw mulches make it relatively easy to practice stubble-mulch farming to keep cover on the land and prevent wind erosion in those areas where straw production exceeds 2,500 pounds per acre per small grain crop.

Data for making comparisons between wind erodibility of stubble-mulch fallow and clean fallow are not extensive. However, some results by Fenster and McCalla (*26*) of 8 years' evaluation of tillage practices for wheat-fallow rotations in western Nebraska have shown the relative wind erodibilities of one-way and clean tillage, to be 63 and 240 percent greater, respectively, than stubble-mulch tillage. Wind-tunnel tests on farmers' fields in western Nebraska in 1957 also clearly demonstrated the superiority of stubble mulch over clean fallow for wind-erosion control [15] (table 4.4). Of

[15] CHEPIL, W. S., and N. P. WOODRUFF. ANNUAL RESEARCH REPORT. Agr. Res. Serv. U.S. Dept. Agr. Manhattan, Kans. 1957.

TABLE 4.4.—*Comparison of effectiveness of stubble mulch and clean fallow in controlling wind erosion in western Nebraska, 1957*

Soil type	Kind of fallow [1]	Wind erodibility [2]	Straw mulch
		Tons/A	*Lb./A*
Keith loam	Stubble mulch	0.4	1,370
Do	Clean fallow	9.8	425
Very fine sandy loam	Stubble mulch	.3	3,645
Do	Clean fallow	16.5	800
Rosebud, very fine sandy loam	Stubble mulch	2.3	1,680
Do	Clean fallow	22.7	480
Keith loam	Stubble mulch	.1	3,780
Do	Clean fallow	1.8	735

[1] Stubble mulch tillage accomplished with 30-inch sweeps as required to control weeds. Clean fallow accomplished by chopping stubble, plowing 6 inches deep, chiseling, spring-toothing twice, and rodweeding twice.

[2] Portable tunnel data adjusted to annual soil loss for field 160 rods long.

particular interest was the remarkable reduction on wind-erosion potential when the straw mulch exceeded 1,000 pounds/acre. This table also reflects much greater wind-erosion erodibility for the sandy loam soil as compared with the heavier loam soil.

Soil erosion by wind in the central Great Plains occurs primarily during the dormant season after wheat has been planted and not during the fallow period itself. Although there are exceptions, as will be pointed out later, the wind-erosion potential of continuous wheat is usually higher than for fallowed wheat. First, the stubble in a continuous wheat system is usually plowed or one-way disked, which leaves little or no mulch to protect the soil surface from planting time until the wheat is tall enough to provide protection the next spring. Second, the fall growth of continuous wheat is usually poor (if it germinates at all) (*49*, *69*). And third, fallow-wheat lends itself to protective stripcropping techniques that are not feasible in a continuous wheat system. Any soil-water shortages during this September to mid-April period for continuous wheat are almost certain to result in winterkill of the plants; thereby magnifying erosion potential when the anchorage of live plants is gone.

Wind erosion can be controlled on fallow land by applying one, some, or all of the four principles of control, namely: (a) Produce or bring to the soil surface aggregates or clods large enough to resist the wind force; (b) roughen the land surface to reduce windspeed and trap drifting soils; (c) reduce field width by strip cropping or by establishing vegetative wind barriers, to reduce windspeed and soil avalanching; and (d) establish and maintain vegetative cover to protect the soil. On summer-fallow land, applying the last principle, which is the "golden" or "cardinal" rule of wind-erosion control, is probably the most important, and this principle can best be applied by practicing stubble-mulch farming (*51*). With today's information and equipment, there is little excuse for wind erosion to occur if sufficient protective vegetative cover can be produced (*16*).

Water

Water erosion has not been a major problem in the semiarid areas of the central Great Plains region. Perhaps it is for this reason that limited information is available on the effect of water erosion from either fallowed or cropped land in semiarid areas.

A definite relation does exist between total runoff and water erosion from agricultural lands. Therefore, the factors affecting runoff also affect erosion (*6*, *30*). The major variables affecting water erosion are climate, soil, vegetation, and topography. However, only the vegetative factor will be considered as it affects erosion on fallowed land. A good vegetative cover, such as a stand of grass offsets the effects of climate, topography, and soil on erosion (*6*, *30*).

At one time or another, about 55 percent of the native grasslands in the central Great Plains have been plowed and put into production of various crops for food and fiber. As might be expected, cultivated land increased the potential for water erosion on sloping land. The following data from an 8-year study at the central Great Plains Field Station near Akron, Colo., summarize the effect of converting grassland to a wheat-fallow rotation on runoff and erosion.[16] It is the fallow period of the rotation when the hazard for water erosion is greatest.

Crop	Runoff *Inches*	Soil loss *Tons/Acre/Year*
Tame grass mixture	1.2	0.2
Wheat-fallow rotation	1.4	.7

The runoff and soil loss were from silt loam soils on 2 to 6 percent slopes. Annual precipitation for the period averaged 15.4 inches. Although the runoff and soil losses were low compared with those in more humid areas, converting grassland to a crop-fallow agriculture increased runoff 14.3 percent and water-erosion potential 250 percent.

Runoff and erosion can be effectively controlled by proper stubble-mulch management on fallowed soils (table 4.5). Duley and Russel (*20*) incorporated straw mulch in the surface soil. Fenster tested black fallow versus stubble fallow in a wheat-fallow rotation (*23*). Mannering and Meyer (*52*) and Adams (*1*) applied loose straw on the surface at the specified rates. Whether straw was incorporated in the soil or applied loose on the surface, results showed substantial reduction in runoff and erosion with increase in infiltration. These effects were accomplished by: (a) Interception of rainfall by absorbing the energy of raindrops and thus reducing runoff, (b) retardation of erosion by decreasing surface velocity, (c) physical restraint of soil movement, and (d) improvement of aggregation and porosity of soil by plant residues.

Soil Fertility

The soil constituents of organic matter (carbon), total N, and available P in the soils are known to be influenced by many factors, including cropping practices. Comparisons of organic matter, total N and available P in soils cropped more than 30 years to continuous wheat versus alternate fallow and wheat at several central Great Plains locations have been reported (*37*, *38*). The organic-matter content of the soil at all locations decreased regardless of cropping systems. The decrease with continuous winter wheat was slightly greater than that with fallowed-winter wheat at Hays, Kans., but was slightly less at Archer, Wyo., and Colby, Kans. The same relation existed for total nitrogen. However, when all types of small grains were considered, generally the loss of nitrogen and carbon was slightly greater from alternate fallow and cropping than from continuous cropping.

Hobbs and Brown (*42*) reported that from 1916 to 1958 at Hays, Kans., the average loss of total N was 15 percent with continuous small grain, 20 percent for alternate small grain and fallow, 33 percent for continuous row crop, and 40 percent for alternate row crop and fallow. These data by Hobbs and Brown do point out that row cropping of any kind is considerably more detrimental to the organic carbon and total N content of soil than are the small grain cropping systems.

Available phosphorus was higher in soils alternately cropped to wheat and fallow than in soils continuously cropped at Colby, Akron, and Archer, but the reverse was found at Hays (*38*).

Crop Yields

Increase From Fallow

At seven field locations in the central Great Plains, a yield-performance comparison was made between winter wheat grown continuously and wheat after fallow. These tests were conducted at Akron, Colo., Alliance, Nebr., Archer, Wyo., Colby, Garden City, and Hays, Kans., and North Platte, Nebr., over a period of 23 to 51 years under average annual precipitation of 15.8 to 22.7 inches. The comparison tests were initiated early in the century and all were terminated between 1945 and 1958. The yield-probability performance of both continuous wheat and fallowed wheat for these locations have been calculated according to the procedure of Friedman and Janes (*29*) and are shown in figures 4.8 to 4.11.

[16] Mickelson, R. H. annual research reports. U.S. Central Great Plains Field Sta., Agr. Res. Serv., U.S. Dept. Agr., Akron, Colo. 1963–70.

TABLE 4.5.—*Effect of stubble mulch on runoff and soil erosion*

Worker and location	Cultural practice	Water runoff	Soil erosion	Infiltration rate
		Percent	*Tons/A*	*Inches/Hr*
	On summer fallow:			
Duley and Russel (*20*)	No straw, disked	42.9	26.8	—
Lincoln, Nebr.	2 tons straw, disked	39.6	16.4	—
(Natural rainfall)	2 tons straw, subtilled	17.7	2.2	—
	Average fallow and wheat:	*Inches*		
Fenster (*23*)	Black fallow	2.16	4.9	—
Alliance, Nebr.	Stubble mulch	.67	1.2	—
(Natural rainfall)				
	Straw mulch applied:	*Inches*		
Mannering and Meyer (*52*)	0 ton/acre	2.8	12.4	3.4
Lafayette, Ind.	1/4 ton/acre	2.5	3.2	3.7
(Simulated rainfall 6.25	1/2 ton/acre	1.6	1.4	4.7
inches at 2.5 in/hr.	1 ton/acre	.3	.3	5.9
over 3-day period)	2 tons/acre	.1	0	6.2
Adams (*1*)	Bare check	7.1	15.7	1.4
Temple, Tex.	2 inches of straw	6.4	Tr.	2.1
(Natural rainfall)				

The yield probability for continuous wheat was much higher at North Platte and Hays than at the other five locations. This could be expected since these two locations have the highest annual precipitation in combination with air temperatures that are not severely restrictive to wheat production. North Platte and Hays also had the highest yield probability with wheat grown on fallow, but the margin over such locations as Akron and Colby was less than for continuous wheat. The poorest yield probability for both continuous wheat and fallowed wheat was obtained at Garden City, Kans. The climatic restrictions at this location include a combination of high average wind velocities and warm temperatures. The impact of temperatures is discussed on pages 72–77.

For the seven locations, the average yield probability at the 10-, 20-, and 30-bushel-per-acre level for wheat-fallow was 66, 38, and 21 percent, respectively, and for continuous wheat the probability for the same order of magnitude of yields was 37, 16, and 6 percent. Wheat failures were experienced 44 percent of the time for continuous wheat for all seven locations as a whole. Excluding the North Platte and Hays locations, a 53 percent failure for continuous wheat was experienced. The primary cause of failure with continuous wheat usually was the lack of sufficient stored soil water at seeding time to obtain a reasonably good stand and to carry the crop through to the succeeding spring without winterkill (*12*, *49*). Available soil water at seeding time seldom exceeds 3.0 inches for continuous wheat, but fallowed soil usually contains over 7.0 inches soil water at seeding time (*12*, *34*, *49*, *69*).

The yield-probability data given in figures 4.8 to 4.11 do not include the comparative performance of wheat-fallow versus continuous wheat since 1953 at any location except North Platte, Nebr., (fig. 4.11). The North Platte data show a much wider spread between these two methods of growing wheat in the 1940 to 1970 period than in the 1912 to 1950 period. These data strongly suggest the impact of improved fallow on wheat yields.

In the western section of the central Great Plains, winter wheat needs at least 9 to 10 inches of water (stored soil water+crop-season rainfall) before any grain is produced (fig. 4.12). The production expectancy rises very sharply thereafter. However, the average soil-water storage in fallow for wheat is not sufficient to produce grain without additional crop-season rainfall. Nevertheless, the more water stored during the fallow season the less wheat is dependent upon supplemental precipitation. Generally,

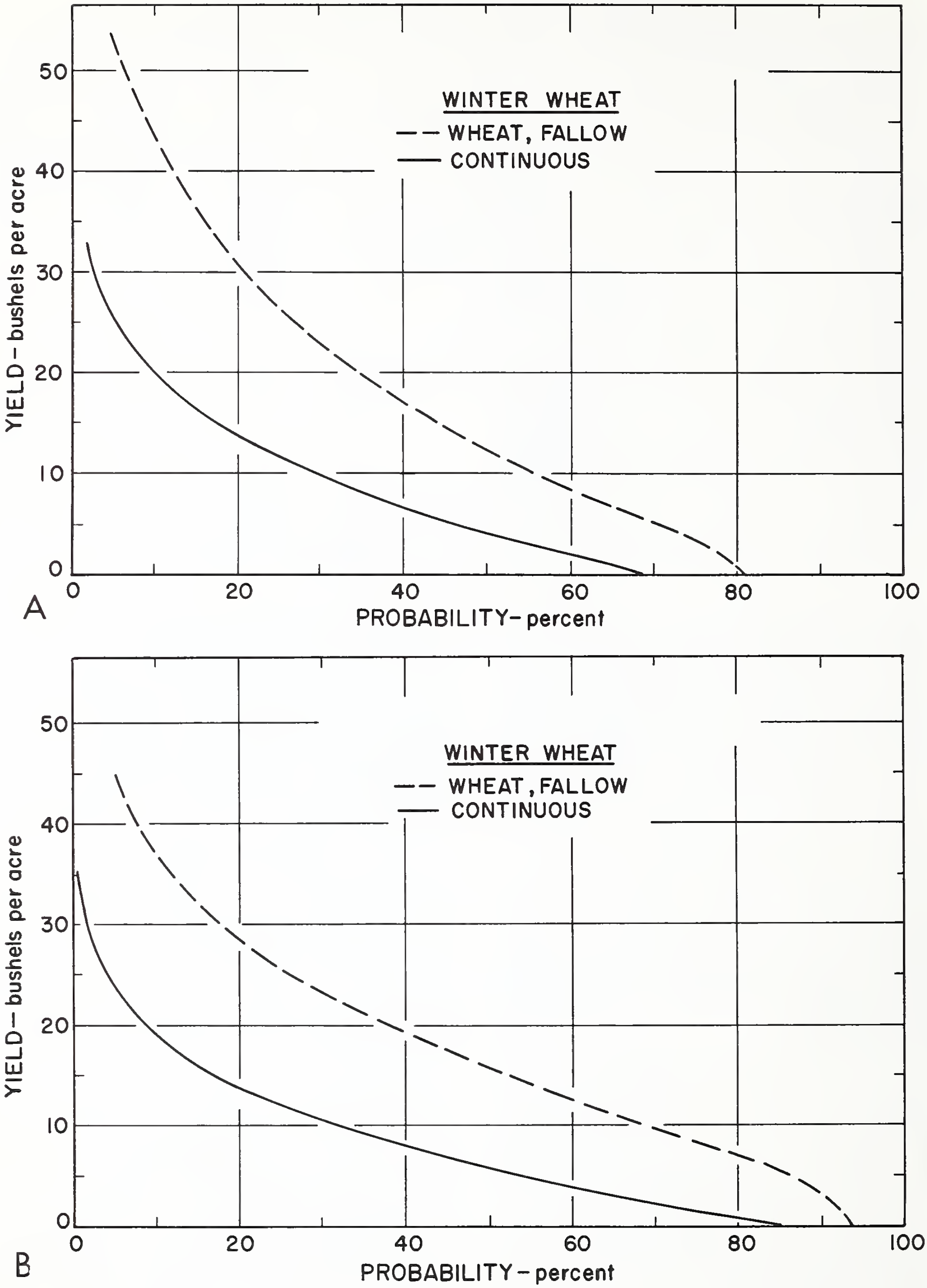


FIGURE 4.8.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at: *A*, Alliance, Nebr., 1931–53; *B*, Akron, Colo., 1909–53.

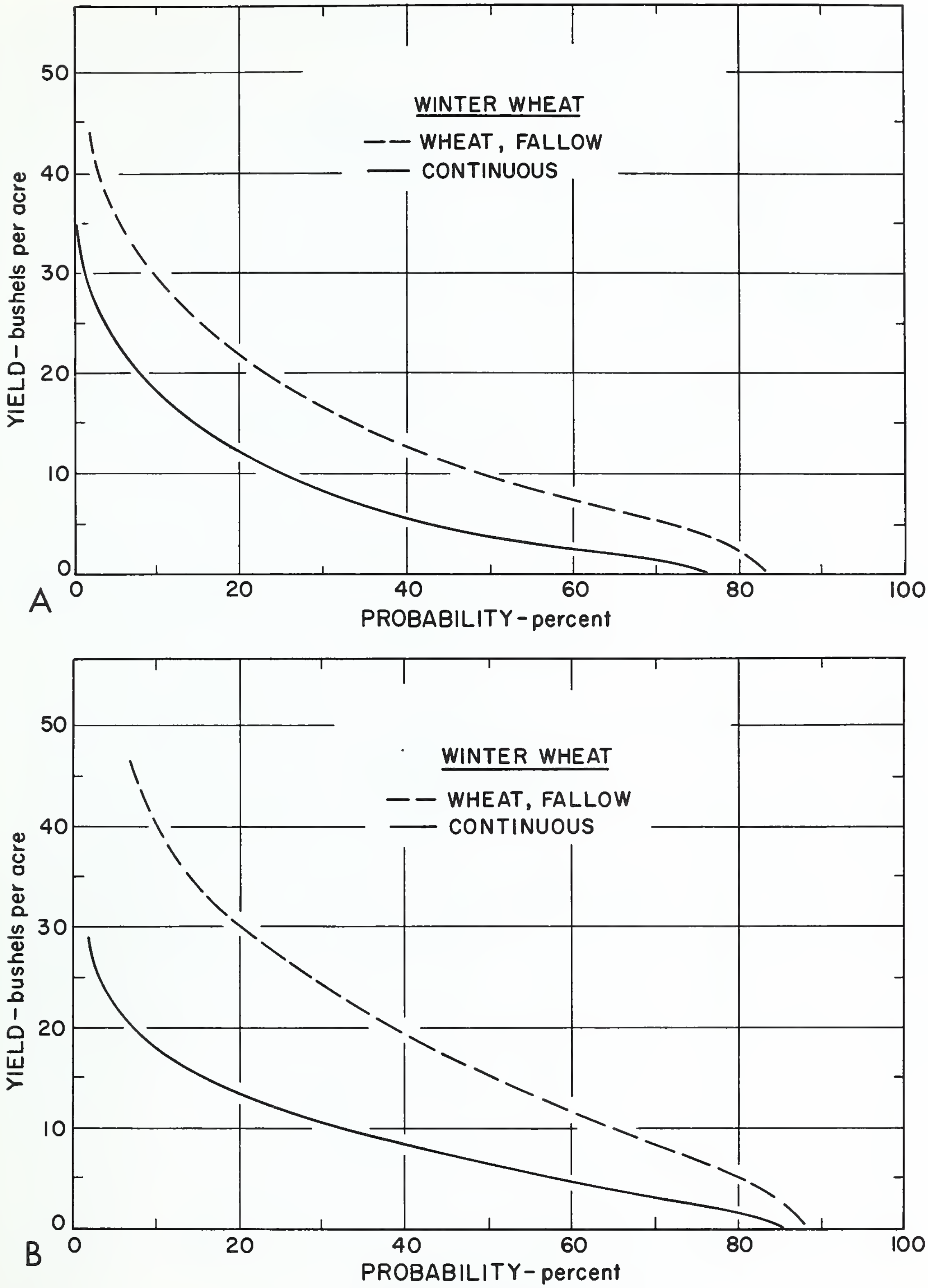


FIGURE 4.9.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at: *A*, Archer, Wyo., 1915-45; *B*, Colby, Kans., 1915–50.

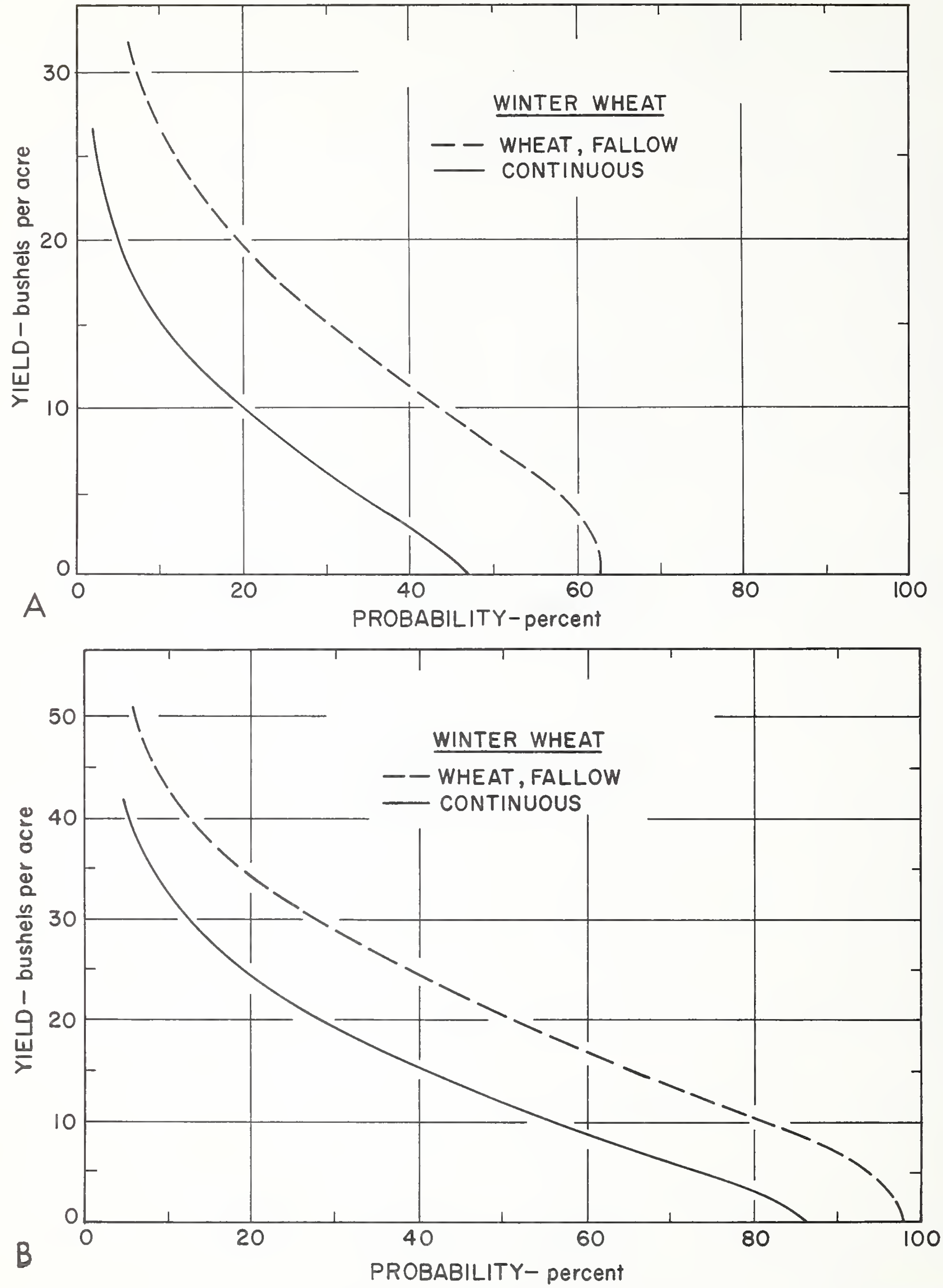


FIGURE 4.10.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at: *A*, Garden City, Kans., 1914–45; *B*, Hays, Kans., 1908–58.

wheat will respond at the rate of 3 to 6 bushels per inch of available water once the minimum water requirements are achieved (*69*).

In addition to the data given for North Platte (fig. 4.11), the data in figure 4.12 show a pronounced improvement of wheat yields on fallow at Akron, Colo. Comparing the 1911 to 1956 period with the 1957 to 1970 period, there has been a net gain of 11.0 bushels/acre with 2.0 inches less average precipitation. These yields were not plot yields alone, but the average of 150 acres per year. Stored soil water during fallow was increased from 4.7 to 6.7 inches net gain with improved fallow despite a 2.7-inch reduction in fallow-season precipitation. The increased yield on fallow since 1956 is probably the result not only of improved water-storage efficiency, but also of better planting equipment and improved wheat varieties.

Water-Use Efficiency

Data pertaining to the comparative long term yields and water-use efficiencies (harvest-to-harvest precipitation basis) of wheat grown continuously and after fallow are given in table 4.6 for Akron, Colo., Colby, Kans., and North Platte, Nebr. With the exception of the 1931–40 period, water-use efficiency of wheat grown on fallow at Akron has gradually increased from 0.60 bushel/acre/inch during the 1911 to 1920 period to about 1.0 bushel/acre/inch since 1958 (table 4.6). In fact, the highest yields of wheat and highest water-use efficiency (1.20 bushel/acre/inch) at Akron were achieved during the 4 years 1967–70 under the lowest average precipitation ever received. Similarly at North Platte, water-use efficiency increased from 0.48 bushel/acre/inch during 1912–20 to 1.10 bushel/acre/inch since 1960. The results at Colby, Kans., have been less impressive than at Akron and North Platte. Nevertheless, water-use efficiency for wheat on fallow did increase sufficiently at Colby to exceed the water-use efficiency of continuous wheat since 1930.

Generally, water-use efficiency of continuous wheat fluctuated, with little or no established

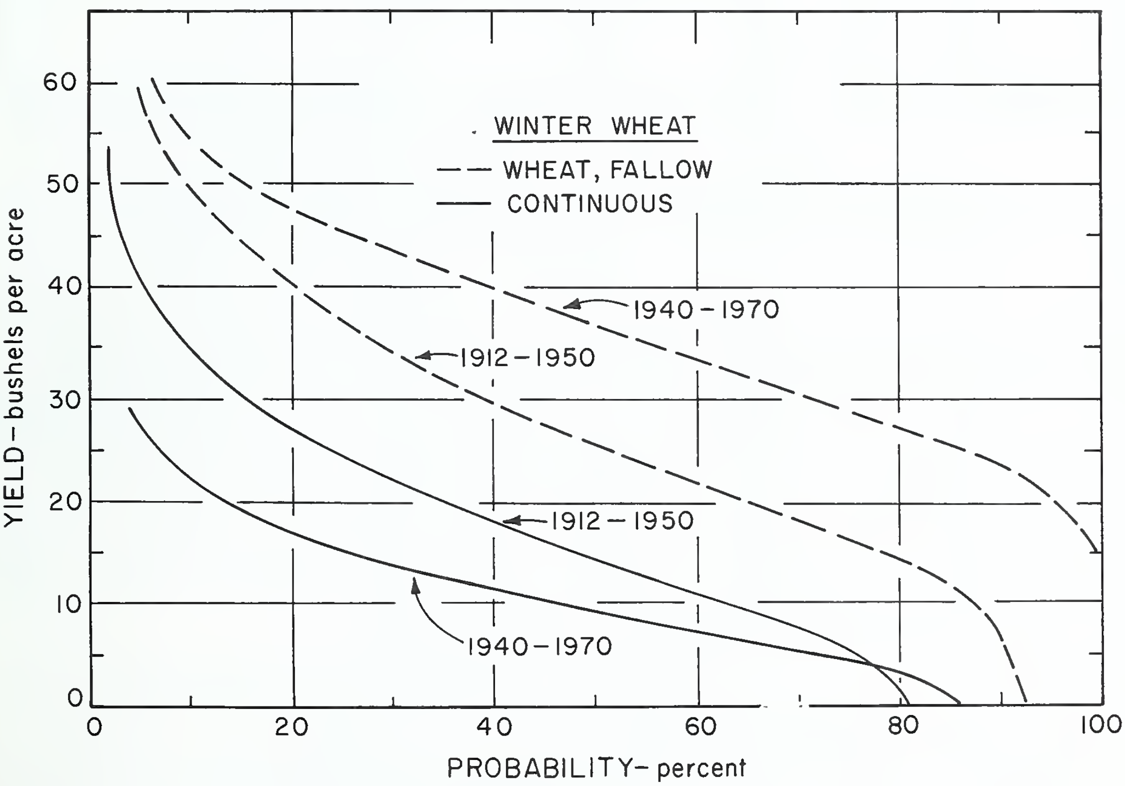


FIGURE 4.11.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at North Platte, Nebr., 1912–50 and 1940–70.

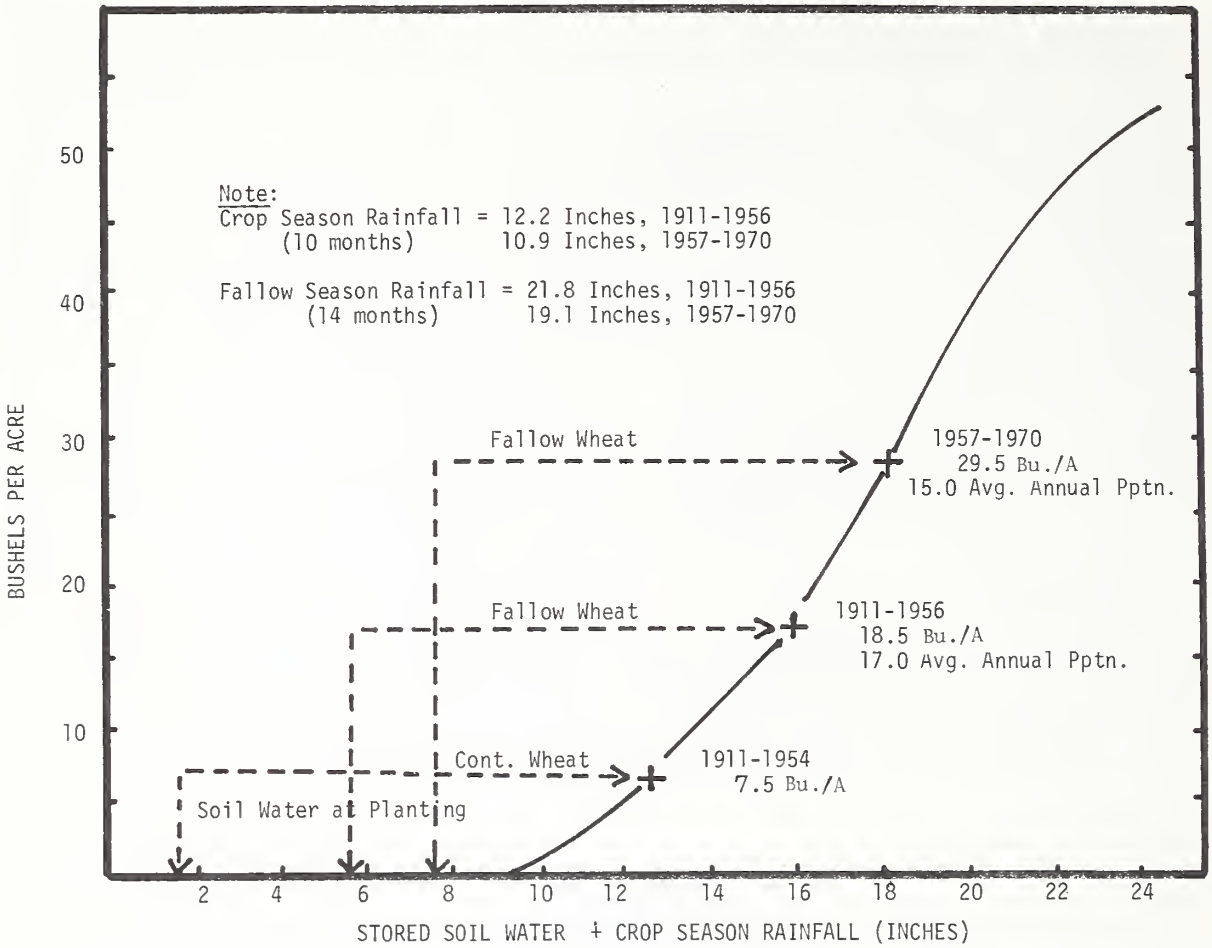


FIGURE 4.12.—General relationship of wheat-yield expectance to available water at Akron, Colo., (NE Colorado). (Stored soil water at seeding = net gain during fallow plus 1 inch residual water from previous harvest.)

trend with time or amount of average precipitation received. When the data from all three locations are combined, the results show that the water-use efficiency of continuous wheat slightly exceeded that of wheat after fallow only up to 1920. Since 1920, the water-use efficiency of wheat on fallow exceeded that of continuous wheat by an ever widening margin. Based on 165 crop years at these three locations, the harvest-to-harvest water-use efficiency of wheat on fallow was 0.67 bushel/acre/inch as compared with 0.53 bushel/acre/inch for continuous wheat.

The average yield of continuous wheat for these same 165 crop years was 9.9 bushels/acre compared with 24.0 bushels/acre for wheat grown on fallow. The ratio of fallow to continuous wheat was 1.21:1 on a total acre basis and 2.42:1 on a per-harvested acre basis. Annual precipitation averaged 18.11 inches during this comparison. Further east at Hays, Kans., with nearly 23.0 inches average precipitation, Luebs (*50*) reported an average yield of 14.4 bushels/acre for continuous wheat and 22.6 bushels/acre for fallowed wheat. Thus, in this wetter area, fallow wheat produced only 78 percent as much wheat on an annual basis as did continuous wheat; this shows that the need for fallow was marginal at best.

Production and Economic Stability

The overall performance of winter wheat in the central Great Plains should also include county and area yields as well as yields from experimental locations. It was stated earlier (p. 57) that a large part of the dryland acreage west of 100° meridian includes most of the fallow-wheat area of the central Great Plains. Considerable variation also exists in mean annual precipitation and prevailing air temperatures across specific parts of this area. Significant differences in the yield expectancy of wheat per acre planted and planted acres abandoned has occurred because of these two important climatic variables (table 4.7). These yield differences were much greater from north to south than from west to east. The highest yields were recorded in the west-northwest nine counties of Nebraska—22.0 bushels/acre planted for a 30-year period. The lowest yields were obtained in the four southeastern counties of Colorado—only 8.9 bushels/acre planted in the same time period.

The data in table 4.7 suggest a net average increase of about 2.0 bushels/planted acre of wheat per inch of annual precipitation above 15.0 inches, as contrasted to a net decrease of 1.5 bushels/planted acres per 1° F. increase in June temperature up to 74°. Thus, from west to east, wheat yields are favored by the gain in annual precipitation but

TABLE 4.6.—*Yield and water-use efficiency of winter wheat grown continuously and after fallow at 3 locations in the central Great Plains*

Location and years	Average annual precipitation	Continuous wheat yield	Fallow wheat yield	W.U.E. [1] Continuous wheat	W.U.E. [1] Fallowed wheat
	Inches	*Bu./A*	*Bu./A*	*Bu./A/In.*	*Bu./A/In.*
Akron, Colo.:[2] (*8, 12, 33, 34*)					
1911–20	18.28	11.4	21.8	0.62	0.60
1921–30	16.87	3.1	14.2	.18	.42
1931–40	14.82	2.9	10.0	.20	.34
1941–50	19.10	12.3	29.4	.64	.77
1951–57	15.31	5.1	20.7	.33	.68
1958–66	14.99	(3)	[4] 26.3	----------------	[4] .88
1967–70	14.20	11.2	[5] 34.0	.79	[5] 1.20
60-yr. average	16.50	7.4	21.2	[6] .44	.64
Colby, Kans.:[7] (*49*)					
1915–20	21.20	12.5	16.7	.59	.39
1921–30	18.60	11.8	21.6	.63	.58
1931–40	13.60	1.6	7.0	.12	.29
1941–50	21.80	12.3	26.8	.56	.61
1951–63	18.50	9.4	[4] 22.9	.51	.62
49-yr. average	18.52	9.3	19.6	.50	.53
North Platte, Nebr.: (*69, 89*)					
1912–20	20.27	14.0	19.6	.69	.48
1921–30	19.32	17.1	35.2	.88	.91
1931–40	15.84	7.6	20.4	.48	.64
1941–50	22.00	13.8	37.3	.63	.85
1951–60	19.49	13.9	[4] 37.1	.71	[4] .95
1961–67	20.24	6.4	[5] 44.5	.32	[5] 1.10
56-yr. average	19.48	12.4	31.9	.64	.82

[1] W.U.E., Water-use efficiency on a harvest-to-harvest precipitation basis.
[2] Greb, B. W. Annual research reports. U.S. Central Great Plains Field Sta. Akron, Colo. 1956–70.
[3] Discontinued.
[4] Advent of modern stubble-mulch fallow.
[5] Advent of fall weed control in new stubble plus stubble mulch.
[6] 51-yr. average.
[7] Colby Branch Experiment Station. Annual reports. Kans. Agr. Expt. Sta. Colby, Kans. 1950–63.

TABLE 4.7—*Climate and wheat production in the fallow-wheat area of the central Great Plains, average of 1941–70*[1] (*17, 28, 47, 59, 79*)

State and district	Major counties	Annual precipitation	Annual snowfall	Annual temperature	June temperature	Planted	Harvested	Acres abandoned	Yield per planted acre	Production
	Number	*Inches*	*Inches*	*°F.*	*°F.*	*1,000 acres*	*1,000 acres*	*Percent*	*Bushels*	*Million bushels*
Nebraska:										
West-Northwest	9	17.5	39	48.5	65.8	835	756	10	22.0	18.4
Southwestern	9	19.6	30	51.2	69.9	705	640	9	21.4	15.1
Colorado:										
Northeast	4	18.0	33	49.7	67.5	547	472	14	18.6	10.2
Northwest	4	15.0	28	48.8	66.2	652	520	20	15.8	10.3
East-Central	4	15.3	28	49.6	67.6	509	373	27	12.5	6.3
Southeast	4	15.4	23	53.0	71.0	707	387	45	8.9	6.3
Kansas:										
Northwest	6	19.9	23	52.9	71.2	1,017	880	13	18.8	19.1
West-Central	7	19.2	22	53.5	72.2	921	723	22	15.7	14.4
South-Southwest	5	19.9	16	56.3	75.1	915	750	18	14.7	13.5
Southwest	6	17.3	19	55.7	74.1	733	547	25	14.2	10.4
Area totals or average		17.8	26	51.9	70.0	7,541	6,048	20	16.4	124.0

[1] GREB, B. W. Climate and cultural practices affecting winter wheat production in 58 counties of the western section of the central Great Plains. Unpublished Rpt. 1960.

this is partly nullified by the increased average air temperatures. Army and Hanson (*3*) showed similar positive and negative relation with precipitation and temperatures, respectively, on yields of spring wheat.

The importance of air temperatures alone in yield probability of wheat is well demonstrated in figure 4.13, which was developed from the long term production data from North Platte, Nebr. (1912–58 data) and Colby and Garden City, Kans. (see figs. 4.9, 4.10, and 4.11). From these records, the probability of obtaining 20 bushels/acre at North Platte with cooler average June air temperatures was over three times greater than at Garden City, Kans. under much warmer June conditions. The Colby, Kans., data are intermediate between these two extremes. These data agree with Thompson (*74*), who concluded that "Wheat is a cool season crop, however, and it appears that in the warmer climate to the south, above average temperatures during the rapid vegetative growth is detrimental to wheat yields."

With equal fertility and management, the evidence presented here for a broad geographic area dramatizes the sensitivity of wheat to available water and air temperatures. These data also show that when prevailing climatic conditions are severe enough, such as in southeastern Colorado, fallow is no panacea for sustained wheat production. In four counties, in this area wheat abandonment averaged 47 percent or several hundred thousand acres, over a 30-year period. Mathews and Brown (*57*) showed conclusively that when the annual precipitation falls below 15.5 inches the chances for crop failure are greatly magnified. Furthermore, these failures tend to occur in distributions of four or more successive years (*57*).

The data presented in table 4.7 and figure 4.13 support the general thesis that from north to south within the wheat-fallow area of the central Great

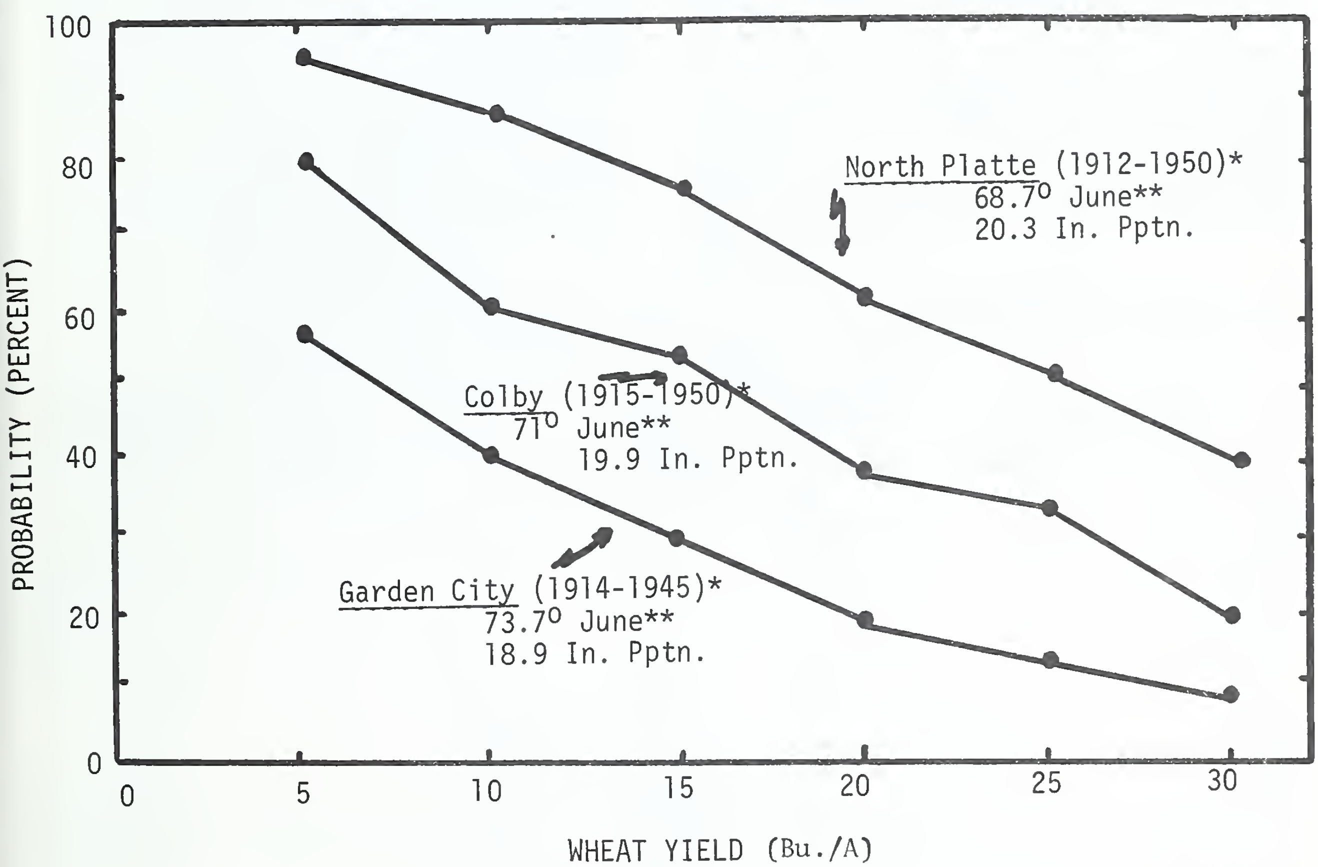


FIGURE 4.13.—Effect of June air temperatures on wheat yield probability on fallow at three central Great Plains locations of similar annual precipitation. (Yield probability data taken from figs. 4.9*B*, 4.10, and 4.11. Weather data, 1938–58 (*79*)).

Plains fallow becomes decreasingly effective. Therefore, the response of wheat to fallow in the southern Great Plains of Texas and Oklahoma could be expected to be much less than in the cooler western part of the central Great Plains.

Within the more favorable wheat-growing areas, such as western Nebraska, evidence in table 4.8 supports the concept that wheat yields are steadily improving. The 13 Nebraska counties selected for long term comparisons show a net gain of 4.3 bushels/acre harvested and 5.3 bushels/acre planted during the 1956 to 1970 period as compared with the 1941–1955 period. Five of the counties—Frontier, Hayes, Hitchcock, Lincoln, and Red Willow—showed a net gain in excess of 7.0 bushels/acre planted from 1956 to 1971. Much of this increased yield actually occurred during the 6 years 1966 to 1971.

These data support on a large geographic scale the same rapid yield increases as being experienced at the individual field stations such as Akron, Colo., and North Platte, Nebr.

There are probably four reasons for the sharp upward yield trend for wheat production in this western Nebraska area: (a) increased soil-water storage in fallow resulting from improved stubble-mulch management and weed control; (b) improved planting equipment that permits deeper penetration to optimum seedbed water, even under relatively dry surface soil conditions of 3 to 4 inches depth; (c) improved wheat varieties; and (d) the increased use of commercial fertilizer on those soils known to be deficient in nitrogen and phosphorus. Professional agronomists and plant breeders in the Colorado-Nebraska area[17] estimated the credit for the 8 bushels/acre increase in wheat yields in Red Willow County, Nebr., to be as follows:

> Improved water storage in fallow, 40 percent;
> improved wheat varieties, 40 percent;
> improved planting equipment, 10 percent;
> use of nitrogen and phosphorus, 10 percent.

Further west in the drier regions of northeastern Colorado, improved planting equipment becomes more important and the use of fertilizer much less so.

The economics of the wheat-fallow system changes drastically from year-to-year in response to yield, prices, taxes, government programs, and changes in management practices, such as cost and size of machinery, acres being farmed, and number

[17] Personal communication with G. O. Hinze and J. R. Welsh, of Colorado State Univ., and P. H. Grabouski and P. T. Nordquist of the University of Nebraska.

TABLE 4.8.—*Gains in yields of dryland winter wheat in western Nebraska (59)*

Section and county	1941–55 average		1956–70 average		Gain, yield per planted acre
	Planted acres harvested	Yield per planted acre	Planted acres harvested	Yield per planted acre	
	Percent	*Bu.*	*Percent*	*Bu.*	*Bu.*
West:					
Banner	89	21.1	88	23.3	2.2
Cheyenne	93	23.8	91	24.6	.8
Deuel	92	22.1	90	26.4	4.3
Kimball	79	15.6	91	21.1	5.5
Southwest:					
Chase	89	20.2	89	22.3	2.1
Dundy	85	18.4	88	22.7	4.3
Frontier	90	17.0	93	24.7	7.7
Hayes	87	16.8	90	24.0	7.2
Hitchcock	88	16.6	92	24.1	7.5
Kieth	92	20.7	93	25.4	4.7
Lincoln	88	16.1	91	23.2	7.1
Perkins	92	20.3	93	24.2	3.9
Red Willow	91	18.3	92	26.3	8.0
Average	89	19.0	91	24.0	5.0

of fallow operations required. Nevertheless, some reasonable averages are available that can be used to estimate a cost-profit comparison between continuous versus fallowed winter wheat. Such a comparison for the 1941 to 1970 period for the Akron, Colo., North Platte, Nebr., and Colby, Kans. locations is shown in table 4.9. The final production costs averaged $9.50 per acre per year for continuous wheat compared with $7.75 for wheat grown on fallow. The net profit on fallowed wheat averaged $16.82 per acre per year compared with only $7.10 for continuous wheat. This profit ratio of 2.37:1 per year in favor of fallow does not include the premium price that is often paid for fallowed wheat because of its higher protein content. With the current prices for wheat and costs of production, including the application of 40 pounds/acre nitrogen, the profit margin in 1970 would be 2.9:1 in favor of wheat grown on fallow.

In any event, there is little evidence, either in yields or economics to justify the use of continuous wheat in the wheat-fallow area of the central Great Plains west of the 100° meridian in terms of grain production alone.

Fertilizer Effects

Nearly all the dryland fertility experiments in the semiarid sections of Kansas, Nebraska, and Colorado have been conducted since 1946. Therefore, some of the more pronounced trends in fertilizer responses are only now emerging. Generally speaking, wheat response to fertilizer has been more consistent with N than with any other nutrient. However, these N responses have varied considerably with time, cropping system, and soil type.

Olson and Rhoades (*62*) and Olson and others, in Nebraska, (*61*), reported on a large number of field experiments with N, P, and NP combinations at low rates on winter wheat from 1946 to 1964. Other data (*62*) showed a net gain of 7.5, 2.9, and 0.3 bushels/acre with nitrogen in south-central Nebraska, west south-central Nebraska, and extreme western Nebraska, respectively. The larger responses reported for south-central Nebraska were for 93 percent continuous wheat; whereas, of the more western two groups of tests, 75 percent were for wheat succeeding fallow. They concluded that nitrate release during fallow greatly reduced the need for supplemental nitrogen (*62*). Nevertheless, there is considerable evidence in more recent years that wheat on fallow in the semiarid section of Nebraska is showing a substantial percent response to N fertilization (*58, 69*). This appears to be a combined product of increased time of cultivation since the land was broken from sod, improved storage of water in fallow, and of increased wheat yields removing substantial amounts of N without replacement (*63*).

TABLE 4.9.—*Average cost-profit comparison between continuous and fallowed winter wheat on a yearly basis for Akron, Colby, and North Platte, 1941–70*

Cost item	Number operations	Continuous wheat	Number operations	Fallowed wheat
		Dollars		*Dollars*
Sweep or oneway	1	1.50	3	4.50
Rodweed	1	1.00	2	2.00
Seed	1	2.00	1	2.00
Harvest	1	3.50	1	4.00
Insurance (hail)		1.50		3.00
Total		$9.50		$15.50
Production cost per year ... dollars		9.50		7.75
Yield per year ... bushel/acre		10.0		[1] 14.8
Protein content ... percent		11		12.5
Sale value of wheat ($1.66) ... dollars [2]		16.60		24.57
Net profit per acre ... dollars		7.10		16.82

[1] Average yield of wheat on fallow divided by two to put on yearly basis.
[2] Average price 1941–70 (*17*).

Table 4.10 shows a State-by-State breakdown of wheat response to N fertilization with continuous cropped and fallowed wheat on medium-textured soils and sandy soils. Since 1952, fallowed wheat on medium-textured soils has responded to N fertilizer 70 percent of the time in Nebraska (*69*) and about 45 percent of the time in western Kansas (*39, 74*). However, there has been no evidence of significant N response with fallowed wheat in Colorado except on sandy soil (*13, 14*). In both Nebraska and Colorado, strong N responses were obtained with continuous wheat on medium-textured soils whenever soil water was not seriously limiting. As pointed out earlier, sandy soils are low in total N; hence, wheat on sandy soils readily show N-responses regardless of cropping system. At North Platte, where growing continuous wheat was attempted from 1940 to 1967, a N response was obtained 84 percent of the time (*69*). The use of N fertilizer with continuous wheat reduced the incidence of failure by 5 percent, but fallow yields without fertilizer were still 2.6 times greater than continuous wheat with fertilizer. Average yield increase for the first 40 pounds of N has been 2.7 bushels/acre on fallow (*69*) and 4.3 bushels/acre for continuous wheat (*58*). Increases to 60 and 80 pounds of N per acre have given little increase in grain yield beyond that obtained with lower rates.

Data collected since 1950 in Nebraska have shown that when nitrate N in the surface 4 feet of soil at seeding is 50 pounds per acre or less a response to N fertilizer can be expected (*69*). One of the virtues of fallow is the release of nitrate N during the fallow period; thus, smaller and less frequent responses to N fertilizer would be expected after fallow. For instance, analyses of noneroded medium-textured soils in eastern Colorado and western Nebraska show about 6,000 to 7,500 pounds/acre total N in the surface 24 inches of soil (*35, 36, 63*). A 1.5 percent release of N per fallow season should supply 90 to 115 pounds/acre nitrate nitrogen at seeding time for wheat. Soil analyses at the end of fallow as determined over a 6- to 10-year period at Akron, North Platte, and Colby have shown average nitrate nitrogen levels of 118, 100, and 120 pounds/acre, respectively, for these locations (*39, 70*). These nitrate nitrogen levels at Akron and North Platte were about 10 to 15 percent less under stubble-mulch fallow than with clean fallow (*70*). Yet, yield increases of winter wheat to 40 pounds/acre N were about 26 percent greater on clean fallow than with stubble-mulch fallow. In addition, wheat yields were higher with stubble fallow than with clean fallow. The higher amounts of stored soil water achieved under mulching had a greater overall yield effect than did the supplemental N

TABLE 4.10.—*Response of winter wheat to nitrogen fertilizer in the western section of the central Great Plains*

State and land type [1]	Cropping system	Field trials	Yield of wheat at N rate of 0 lb./A	Yield of wheat at N rate of 30–40 lbs./A	Average gain
		Number	*Bu./A*	*Bu./A*	*Bu./A*
Nebraska (62, 61, 58):					
Hardland	Fallow	80	28	33	5
Do	Continuous	49	13	20	7
Sandyland	Fallow	11	24	36	12
Colorado (13, 14, 35, 36):					
Hardland	Fallow	26	28	27	−1
Do	Continuous	8	11	17	6
Sandyland	Fallow	7	14	19	5
Do	Continuous	4	11	15	4
Kansas (39, 40, 73):					
Hardland	Fallow	30	34	36	2
Sandyland	Fallow	8	24	31	7

[1] Hardland—loam, silt loam, and clay loam soils.

[2] Greb, B. W. Annual research reports. U.S. Central Great Plains Field Station, Agr. Res. Serv., U.S. Dept. Agr., Akron, Colo. 1956–70.

application. Interactions of available water and nitrogen on crop yields are common in these drier climates.

Phosphorus is the only other nutrient to which wheat has responded with any degree of consistency in this area. However, response has been limited to sandy soils and eroded medium-textured soils, which have less than 25 pounds per acre of available P in the 4-foot profile at seeding (*8, 13, 73*). These results were obtained with fallow-wheat, but it is believed that similar responses would be obtained with continuous wheat grown on low-fertility soils.

Crop Quality

Protein

The protein content of wheat grown after fallow averaged 12.4 percent compared with only 11.1 percent for continuous wheat at North Platte from 1940 to 1967 (*69*). However, reports (*66, 72*) have shown that the protein content of wheat grain in the semiarid central Great Plains is declining with increasing years of cropping. These reports are based on fallow-wheat because not enough continuous wheat is grown west of the 100° meridian to establish a trend. However, a similar or even greater decrease would be expected with continuous wheat since protein content of the grain is largely controlled by the amount of nitrate-N and available soil water in the profile at seeding. On the average for this area, every pound of nitrate-N above 30 pounds per acre at seeding increases protein content 0.064 percent (*69*). On the other hand, every inch of stored soil water at seeding above 3 inches will decrease protein content of grain 0.57 percent (*69*). This would be of little consequence with continuous wheat, since on the average only 1.8 inches of water can be expected to be stored in the soil at seeding of continuous wheat (*49, 69*).

Protein content of wheat grain is decreased by rains greater than 0.5 inch occurring 40 to 55 days before maturity when little or no rain has been received before this period.[18] Rain at this time also increases the number of tillers, which produce heads after most of the N has already been taken up by the plants. Thus, the N previously taken up must be translocated to more heads; this results in less N per head and subsequent lower protein of the grain. Since continuous wheat must be grown solely from annual precipitation without the benefit of stored soil water, it is believed that rain 40 to 55 days before maturity would have a greater effect on decreasing protein content of continuous wheat grain than in fallow-wheat grain.

Forty pounds per acre of nitrogen fertilizer applied at or shortly before seeding or topdressed in early spring increased protein content of fallow-wheat grain an average of 1.7 percent (*69*). Protein content of continuous wheat increased by only an average of 1.3 percent with 40 pounds of N per acre (*14, 69*). Thus, fallow-wheat appears to utilize fertilizer nitrogen for increasing protein content of the grain as efficiently as, or more efficiently than, does continuous wheat.

Test Weight

Unless the test weight of wheat drops below 58.0 pounds per bushel, there is little effect on sale value. Test weights have not been as materially influenced by tillage methods [19] (*26*) as by varieties, use of nitrogen fertilizer (*13, 14, 58*), disease, and hot, dry winds near maturity (*66*).

Fertilization exceeding 30 pounds/acre of nitrogen tends to reduce test weights of wheat, particularly when there is water stress (*13, 14, 58*). The use of phosphorus in combination with nitrogen tends to overcome the negative effects of nitrogen alone (*13, 26, 58*). Early maturing wheat varieties usually have higher test weights than later maturing ones, because hot dry weather is more prevalent during the latter part of the growing season (*58*). Wheat grown continuously tends to have lower test weights than wheat grown after fallow because of the increased frequency of water stress.[19]

Summary and Conclusions

Climate and Need for Fallow

In 1970, 12.7 million acres were being fallowed in the central Great Plains. The 3.1 million acres of fallow in the "fallow transition" area of south-central Nebraska and north-central Kansas are in a

[18] Smika, D. E. SOIL MANAGEMENT INVESTIGATIONS. North Platte Expt. Sta. Unpublished data. 1960–70.

[19] See footnote 17, p. 76.

climatic area in which fallow is optional. The fallow acreage then may be expected to vary from year to year and from farm to farm with economic and soil-water conditions and type of rotation being practiced. Data by Smika and others have shown that fallow may still be very economical in the western half of this "fallow transition" area (*69*). Good to excellent yields are obtained for wheat and sorghum with the popular fallow-wheat-sorghum rotation (*50*, *64*, *71*). This rotation also lends itself to the substitution of chemicals for certain tillage operations in effectively controlling weeds during the 3-year rotation cycle. Even though soil water often penetrates 6 to 8 feet deep during the fallow, this water can be used by winter wheat effectively (*48*). There seems to be little need for fallow, however, where the annual precipitation exceeds 24 to 25 inches. Thus, fallow on about 1.4 million acres in the "fallow transition" area could be discontinued and replaced by annual crops for improved economic and soil-conservation purposes.

West of the 100° meridian, where the annual precipitation ranges from 11 to 22 inches, the practice of fallow is mandatory for the production of grain crops, and for winter wheat in particular. Temperature and precipitation both play a major role in yield expectancy and risk of acreage abandonment in this semiarid area. Nevertheless, fallow does stabilize yields and reduce the level of risk when compared with continuous cropping for grain.

In east-central and northeastern Colorado, southeastern Wyoming, western and southwestern Nebraska, and most of western Kansas, operators should be able to maintain moderate to good wheat yield expectancy on fallow with a relatively low risk with today's improved knowledge and equipment. Thus, most of the 8.6 million acres now being fallowed should remain fallowed. However, about 300,000 to 500,000 acres of steep land and land with shallow soil profiles should be used for purposes other than fallow.

The elimination of undue reliance on disk-type implements would go a long way toward reducing wind-erosion potential in this large fallow area. Research has provided sufficient information about stubble mulching and more timely weed-control techniques to significantly increase yields and reduce risk to low levels throughout this area. The average percent abandonment of about 20 percent of wheat acres could conceivably be reduced to less than 12 percent by using these new methods of fallow.

The high risk area of southeastern Colorado and the adjacent fringe of southwestern Kansas, which average 47 percent abandonment of wheat, poses an agricultural dilemma. If the land is to be cultivated and cropped, then fallow is probably needed. Unfortunately, this area has a long history of a boom and bust wheat economy, a high percent of absentee ownership, and the poorest application of soil and water conservation practices of any area in the central Great Plains. There seems little doubt that improved farming practices would reduce the percent crop abandonment; but whether this would be sufficient to upgrade the area to the plus side economically remains doubtful at present farm prices. The low P-E index, high average wind velocities, the high coefficient of variation of precipitation, and the magnitude of relative wind-erosion potential are conclusive evidence against continued dry farming in this region except in extreme food-shortage emergencies. About 2.0 million acres of cultivated land (1.0 million of fallowed plus 1.0 million planted) should probably be retired in this area.

Advantages and Disadvantages of Fallow

The advantages and disadvantages of fallow versus continued wheat in the central Great Plains may not apply to other wheat-growing areas of the United States. The whole central Great Plains is a winter-wheat area, and, therefore, the threat of erosion potential is not so great as in a spring-wheat area. For winter wheat, the fallow period is only 14 months, the stubble is upright during the single winter, and by the next spring rains tend to keep fallow fields from wind erosion although some water erosion may occur. The greatest erosion potential occurs after the wheat is planted in the fall and going through a relatively dry, cold, 6-month period. For spring wheat, on the other hand, the fallow period is 21 months, with two winters with little or no soil protection during the second winter. It is during the second winter and spring of fallow that the erosion potential of spring wheat reaches its maximum. Therefore, the threat of erosion during fallow for winter wheat is minimal compared with that for spring wheat on fallow.

The advantages of winter wheat grown on fallow west of the 100° meridian in central Great Plains compared with continuous wheat are as follows: (a) higher average yearly yields of grain; (b) higher average yields of straw for mulching; (c) higher protein content of grain; (d) less risk of dry seedbed; (e) less field operations per bushel produced; (f) more efficient per unit of evapotranspiration; (g) less wind erosion risk; and (h) less influenced by intermittent periods of drought. The only two advantages for continuous wheat are fewer tillage operations per crop and, possibly, the use of continuous wheat as forage hay, which makes an earlier harvest date possible.

All the evidence supports an overwhelming advantage for the fallow-wheat rotation as opposed to a continuous wheat system in the semiarid central Great Plains west of the 100° meridian if only grain production is considered. Nevertheless, under certain economic and modified management techniques, there may be a place for the strategic use of some continuous winter wheat or other fall-planted small grains, or both.

Alternatives for Fallow

For grain production alone, northeastern Colorado, western Nebraska, and southeastern Wyoming have few alternatives to wheat. The climate is too cold and dry for dependable grain sorghum production. Grain sorghum becomes economically feasible only when precipitation exceeds 19 inches and mean yearly temperature is above 52° F. Thus, a fallow-wheat-sorghum rotation is less feasible in those areas that need greater crop rotation diversity. Winter barley is not considered safe because of susceptibility to winterkill. This leaves rye, spring barley, spring wheat, oats, millet, and forage sorghum as substitute crops. Yet, the limitations for these are also imposing: (a) Hot weather when grain is ripening consistently causes grain shriveling of spring barley and oats; (b) water requirement for oats is excessively high per pound of dry matter produced; (c) there is little sale value for rye as grain; (d) spring wheat has a low yield capacity; (e) grain millet can be highly productive under optimum mid-summer rainfall conditions. However, present varieties of grain millet tend to shatter excessively, do not grow tall enough for direct combine harvest, and the grain does not ripen uniformly; and (f) all spring-planted small grains tend to become excessively weedy in this area and this is a nuisance at harvest.

It has also long been known that spring-planted small grains have not responded to fallow nearly so well as fall-planted types (*12*, *49*, *50*, *54*, *89*). Spring-planted small grains do not develop a deep root system, and thus do not take advantage of the deep soil water in fallow.

Growing some of these crops for continuous hay instead of grain may remove some cultural restrictions. For example, at Akron, cutting winter-wheat hay in the early heading stage of May 20 to June 1 (or grazing wheat to the same date) and immediately undercutting would extend the soil-water storage time by 6 weeks, or an expected soil-water storage of 3.7 inches. In contrast, the expected soil-water storage for continuous wheat for grain would be but 2.0 inches. The comparative expected yields would be 480 pounds per acre as grain and 2,200 pounds per acre as hay (*12*).

The potential for continuous wheat as a forage crop to survive the dry winter-dormancy period, therefore, would be much greater than if grown continuously for grain. Barriers of wheatgrasses or sudangrass (*10*, *31*) could also be used to trap additional snow water onto continuous wheat-hay plantings. This scheme needs to be explored. Winter rye grown continuously for hay may prove more hardy and have a higher water-use efficiency than continuous winter-wheat hay. Some of the newer strains of high yielding hay- and grain-type millets have not been tested under fallow-millet, fallow-wheat-millet, or continuous millet.

Although spring-seeded small grains do not have deep-rooting habits, 2.5 feet of Rago or Keith soil at field capacity contains 5.5 inches available water. This amount of stored water at seeding time was probably seldom achieved for continuous spring grains in the old rotation studies (*12*, *49*, *56*). It is highly doubtful if these studies included a good fall weed control program after harvest of spring grains as is now used. An additional 1 to 2 inches of soil water can be stored with this technique (*71*). Better weed control in conjunction with snow-control practices could conceivably increase soil-water storage by an average of 2 to 3 inches above that achieved by older cultural systems. In all cases, when soil-water conditions do become optimum, then additions of N could be used to increase quantity and quality of crops.

Today's new water conservation systems for better mulching, extended weed control by tillage or herbicides, or both, snow control, and fertilizer practices have proved highly successful under most fallow conditions in the central Great Plains. It seems likely that some of these new practices would prove beneficial under continuous cropping as well. Thus, research should be conducted at several central Great Plains locations to test these new conservation techniques with a number of small grains grown continuously in terms of total dry-matter output, and not for grain alone.

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CHAPTER 5.—SUMMER FALLOW IN THE SOUTHERN GREAT PLAINS[1]

W. C. Johnson, C. E. Van Doren, and Earl Burnett[2]

Introduction

The southern Great Plains region includes the States of Oklahoma, Texas, and New Mexico (see fig. 1.8). The main concentration of dryland wheat acreage in the region is in the High Plains, Rolling Red Plains, and Reddish Prairies land resource areas (figs. 5.1 and 5.2) (*1*). A minor concentration is found in the Blackland Prairie and a still smaller acreage in the Grand Prairie. The sparse distribution of dryland wheat raised in the western part of the Rolling Red Plains is partly caused by the breaks, shallow soils, and sandy lands that occupy much of this area and which are unsuited for wheat production.

The climate, soils, and topography of the northern half of the Texas High Plains are well suited to large-scale mechanized wheat farming. Before 1933 and before acreage controls and the large-scale expansion of the High Plains irrigated acreage, over 80 percent of the wheat acreage in Texas was in this area (*5*). Similarly, in the Reddish Prairies of Oklahoma, slopes and soils favor economical, mechanized wheat farming in large units. This fact, coupled with reliable but not excessive rainfall, makes this region the "breadbox" of Oklahoma (*7*).

Most of the dryland wheat acreage raised on summer-fallowed land is in the drier High Plains area in the Oklahoma and Texas Panhandles and eastern New Mexico (fig. 5.3).

In figure 5.4, the average fraction of the dryland wheat acreage raised on fallow for the 3 years 1968–70 is shown for selected areas. The largest fraction, 50 percent, was in the western half of the Texas Panhandle.

Climate

Precipitation in the southern Great Plains has an east-west gradient, and the isohyetal lines have a north-south alignment (fig. 5.5). The annual precipitation in the main wheat-growing region ranges from about 35 inches along the eastern boundary of the Reddish Prairie of Oklahoma to only 16 inches in the High Plains of eastern New Mexico. The amount of precipitation received depends on position relative to the source of supply of moisture, the Gulf of Mexico. The average large-scale flow of moisture from the Gulf is to the northeast along a curved path of clockwise rotation. East of a line extending northward from the western edge of the Gulf, the isohyetal lines are closely spaced. West of that in western Oklahoma and the Texas Panhandle, the precipitation gradient is much less.

Although rainfall in the southern Great Plains is generally of the Great Plains type—characterized by a pronounced summer maximum—, some regional differences in the distribution of monthly precipitation occur (fig. 5.6). In the High Plains area, as at Boise City, Okla., and Bushland, Tex. (fig. 5.7), a single maximum in monthly precipitation occurs in May or June. Farther east, as at Cherokee, Lawton, and Norman, Okla., a secondary maximum occurs in September and October. The secondary maximum at the eastern locations is important because it occurs near wheat-seeding time and, combined with a higher annual precipitation, adds to the certainty of obtaining stands without summer fallowing.

Temperature, as well as the amount of precipitation, affects the water available for wheat production. In addition to the effect of latitude, a marked temperature effect occurs in the southern

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Great Plains owing to a steep east-west gradient in elevation. As elevation increases and temperatures become cooler, an inch of rainfall is thus more effective in crop production in the High Plains than in the Reddish Prairie. At the latitude of the Texas Panhandle, elevations range from 1,000 feet in the Reddish Prairies to 4,500 feet in eastern New Mexico. The gradient in elevation is in the range of 1,000 to 1,300 feet per 100 miles.

The Thornthwaite P-E Index was designed to take into account the temperature factor in precipitation effectiveness (*23*). The lines of equal P-E Index plotted in figure 5.8 reveal a dry region extending from eastern New Mexico into the Oklahoma Panhandle, where the largest percentage of the dryland wheat acreage on summer-fallowed land is found. The P-E Index line of 32 passing through the central Texas Panhandle has special significance because it is the boundary between subhumid and semiarid climatic zones (*23*). Zingg and Whitfield also suggested that the 32 P-E Index line separated the drier area, where stubble-mulch tillage gave higher yield than inversion tillage from the wetter areas where inversion tillage produced higher yields than stubble-mulch tillage. In other words, the P-E Index of 32 approximately separates an area where water is more limiting than fertility in wheat production from an area where fertility is more limiting than water. It also corresponds to a boundary suggested by Throckmorton and Myers

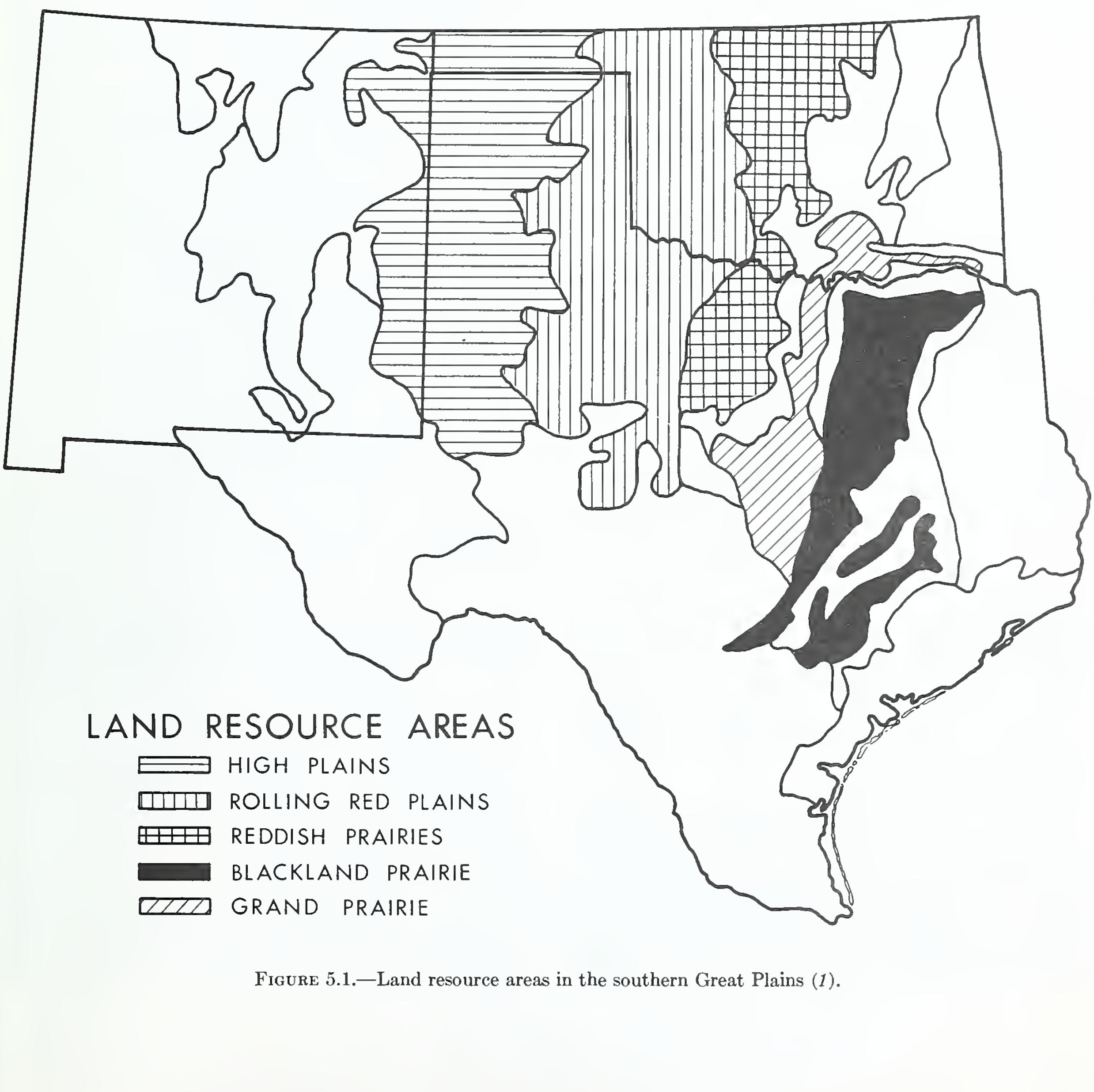


FIGURE 5.1.—Land resource areas in the southern Great Plains (*1*).

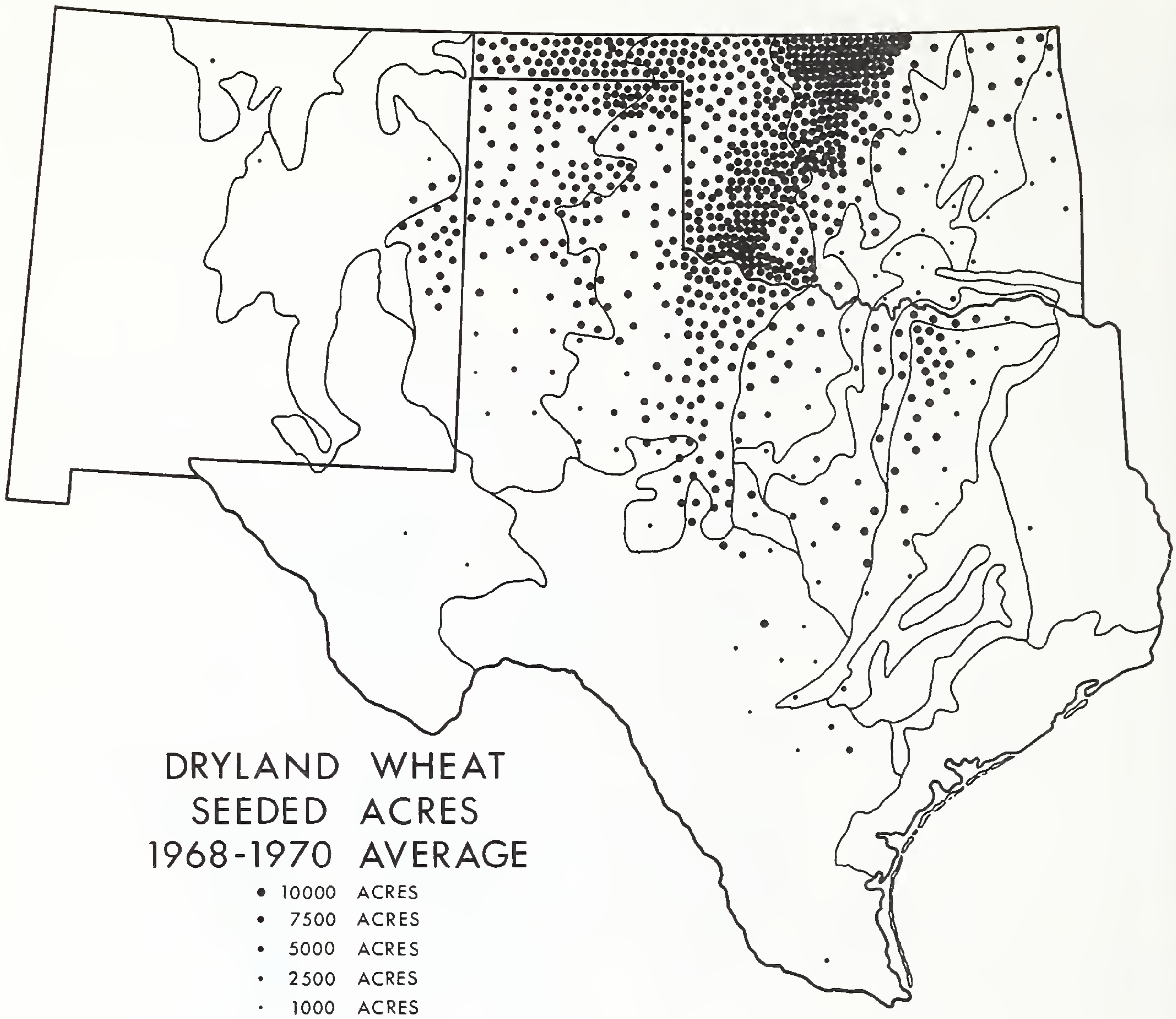


FIGURE 5.2.—Average seeded acres of dryland wheat, 1968–70.

(*24*) west of which, because of aridity, it was recommended that summer fallowing be the standard method of wheat production.

Since the contours of elevation and the isohyetal lines tend to be parallel, the overall patterns of the P-E Index and isohyetal lines have a similar appearance (figs. 5.5 and 5.8).

The effect of elevation on climate is more strikingly revealed by plotting the length of frost-free period (fig. 5.9). If the length of frost-free period were solely determined by sun angle, the iso-lines in figure 5.9 would be aligned horizontally, parallel to parallels of latitude. However, the vertical alignment of the contour lines of elevation at right angles to the parallels of latitude, through its effect on temperature, causes a striking east-west dipping downward of the lines of equal frost-free periods. For example, Bushland, Tex., has the same length frost-free period as Leavenworth, Kans. (fig. 5.7), which is located 300 miles farther north. Bushland has an elevation of 3,800 feet, but Leavenworth has an elevation of only 800 feet. The east-west gradient in length of frost-free period at the latitude of the Texas Panhandle is in the range of 10 to 13 days per 100 miles and amounts to about 10 days' decrease per 1,000-foot increase in elevation. Bushland has a 3 or 4 weeks shorter frost-free period than Norman, Okla., which is at about the same latitude but 260 miles to the east and at an elevation of 1,200 feet compared with 3,800 feet at Bushland. Thus, the east-west rise in elevation increases the precipitation effectiveness for wheat production primarily by lowering temperatures.

Soils

High Plains

The fine-textured soils on which most of the wheat is grown in the High Plains of the Texas and Oklahoma Panhandles occur, for the most part, on nearly level land of less than 1-percent slope.

The High Plains wheatland soils are derived from Tertiary parent material and have adequate fertility so that a response to fertilizer is not obtained under dryland conditions (*3*). In fact, soil tests indicate that there is apt to be an excess of available nitrogen. The benefit derived from summer fallowing in the High Plains, therefore, is solely from water stored and not from an increase in available nitrogen or phosphorus.

Rolling Red Plains and Reddish Prairies

The Rolling Red Plains and Reddish Prairies comprise what Bennett (*2*) termed "the Red Plains

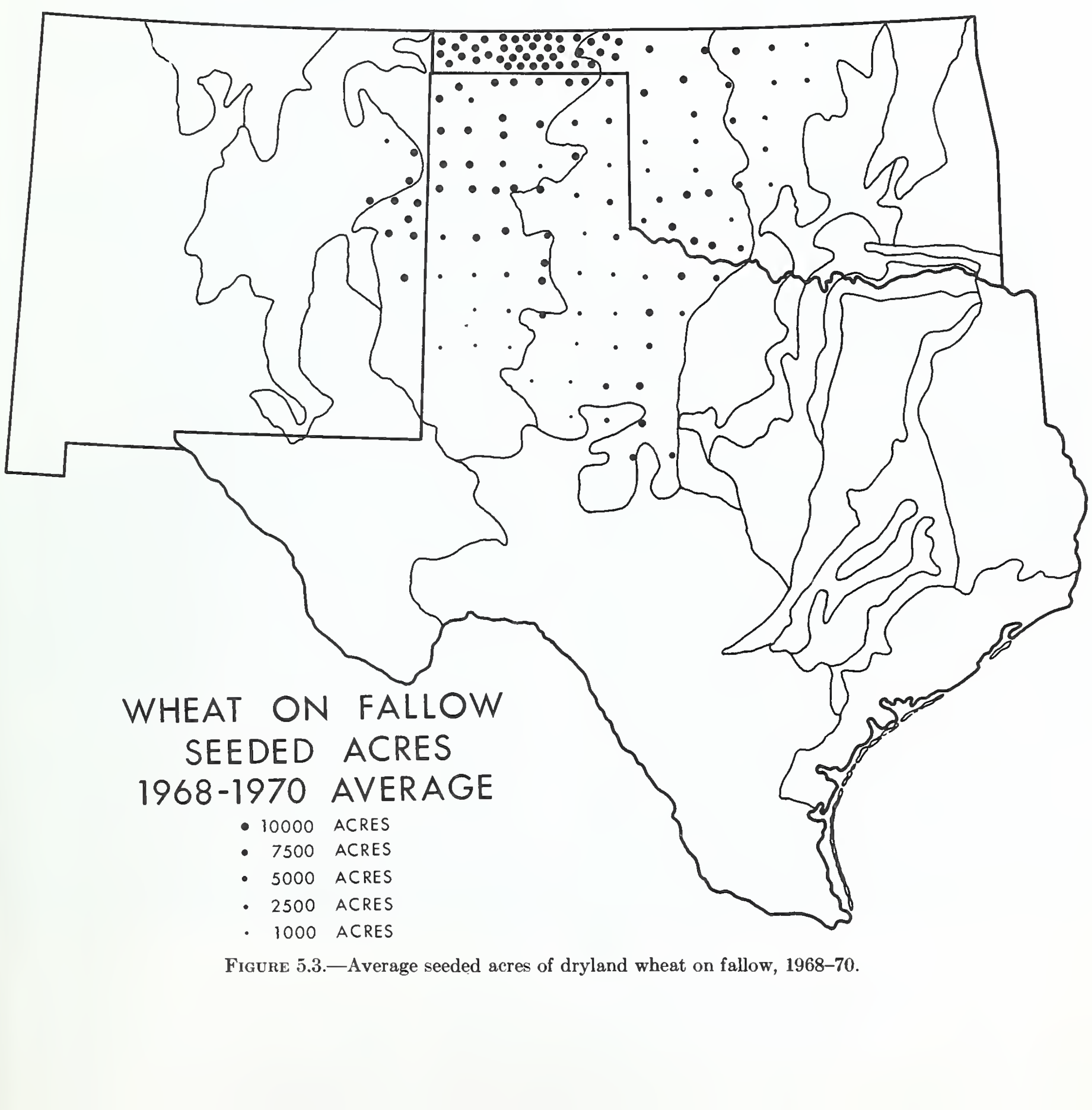


FIGURE 5.3.—Average seeded acres of dryland wheat on fallow, 1968–70.

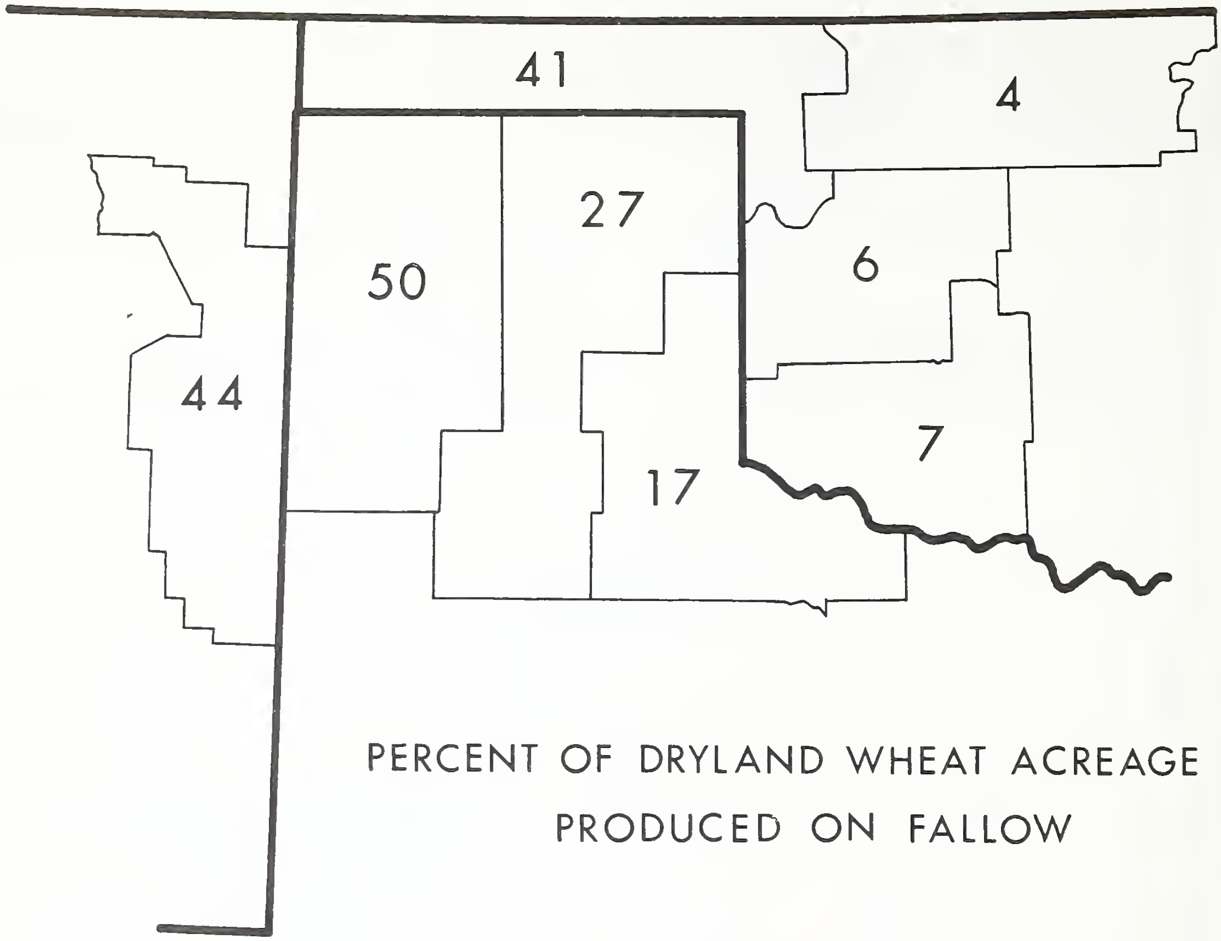


FIGURE 5.4.—Average percent of wheat acreage on fallow, 1968–70.

Problem Area." He stated that this area, despite its short period in cultivation, was exceeded in severity of soil erosion by few other locations in the United States.

The soils of the Rolling Red Plains and Reddish Prairies are derived from Permian materials and are not only erosive but also have nutrient deficiencies. Harper (*9*) reported that the average yield of continuous wheat for 59 years, 1899 to 1957, on a Reddish Prairie Kirkland loam (fine, mixed, thermic Abruptic Pachic Paleustolls) was 20.2 bushels/acre when manure was applied and only 12.6 bushels/acre when not manured. The yield increase from manuring, then, was mainly due to the phosphorus supplied. Similarly, at Lawton, Okla., in the Rolling Red Plains it was concluded as early as 1947 that fertility rather than moisture was the limiting factor in yields (19). The principal nutrient deficiency was phosphorus for all crops tested, with the possible exception of grass for seed production. More recent reports of fertility trials in Oklahoma, although still recognizing phosphorus as being the leading deficient element, attach almost as much importance to an increasing need for nitrogen (*4*).

Nitrogen fertility of a soil is partly dependent on the tillage method and cropping system used. Because of less thorough mixing and aeration of the soil, stubble-mulch tillage, compared with clean tillage with the moldboard or one-way plow, results in less release of nitrogen available to plants and may accentuate an existing need for nitrogen. Schlehuber and Tucker (*22*) reported that in the Reddish Prairies section of Oklahoma, stubble-mulch tillage commonly results in lower wheat yields than clean tillage. The specific example of a test at Cherokee was cited in which the average yield of wheat was 10.3 bushels/acre less if stubble mulch rather than clean tillage were used—25.1 compared with 35.4 bushels/acre. If 40 pounds/acre of nitrogen were applied, the yield difference was only 1.7 bushels/acre. It would be expected that the remaining yield deficit was partly due to increased disease damage on stubble-mulched land in this higher rainfall zone. The soil type is Grant very fine sandy loam (fine, silty, mixed, thermic Udic Argiustolls).

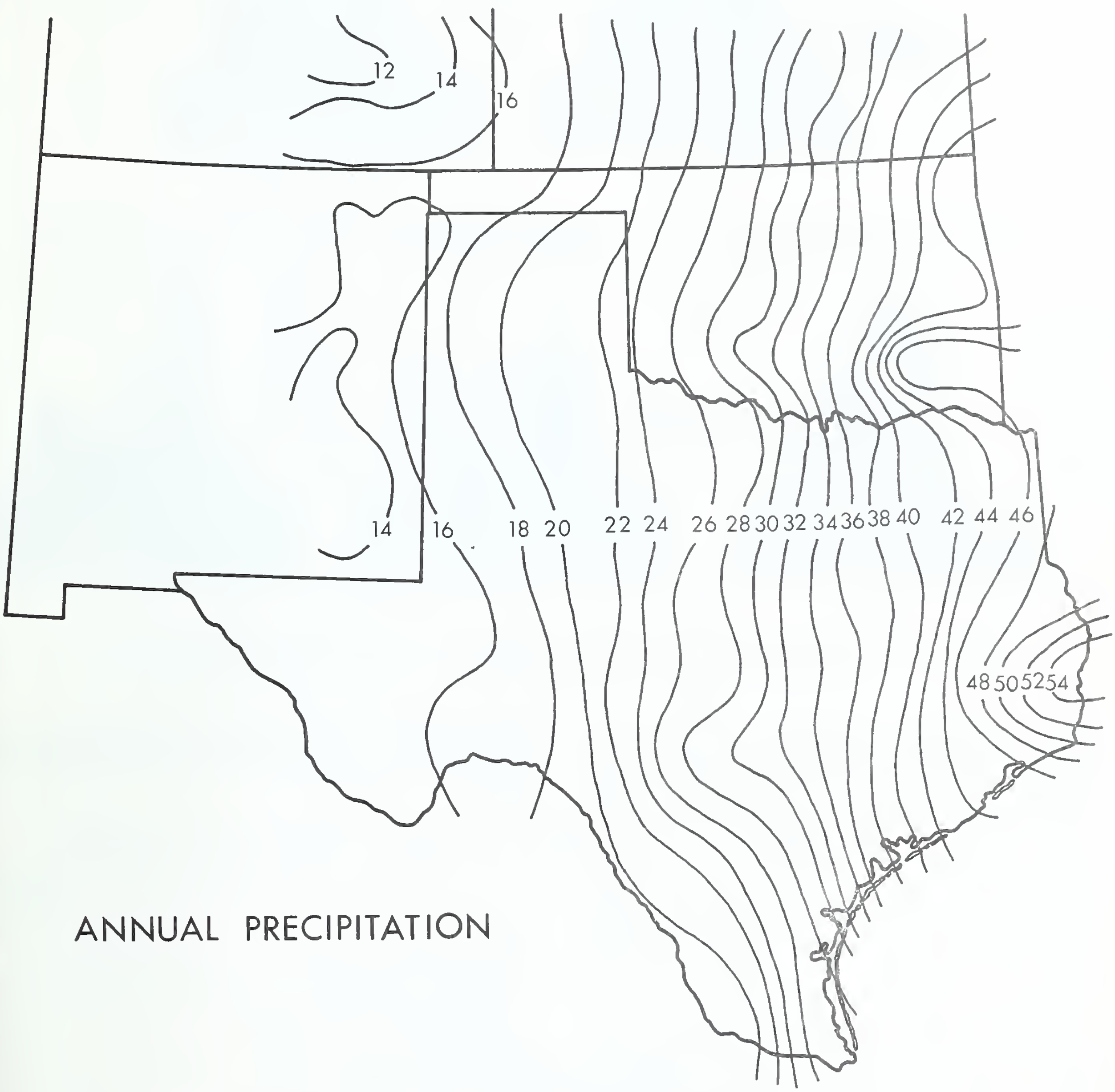


FIGURE 5.5—Average annual precipitation, in inches, 1921–50. (U.S. Weather Bureau data.)

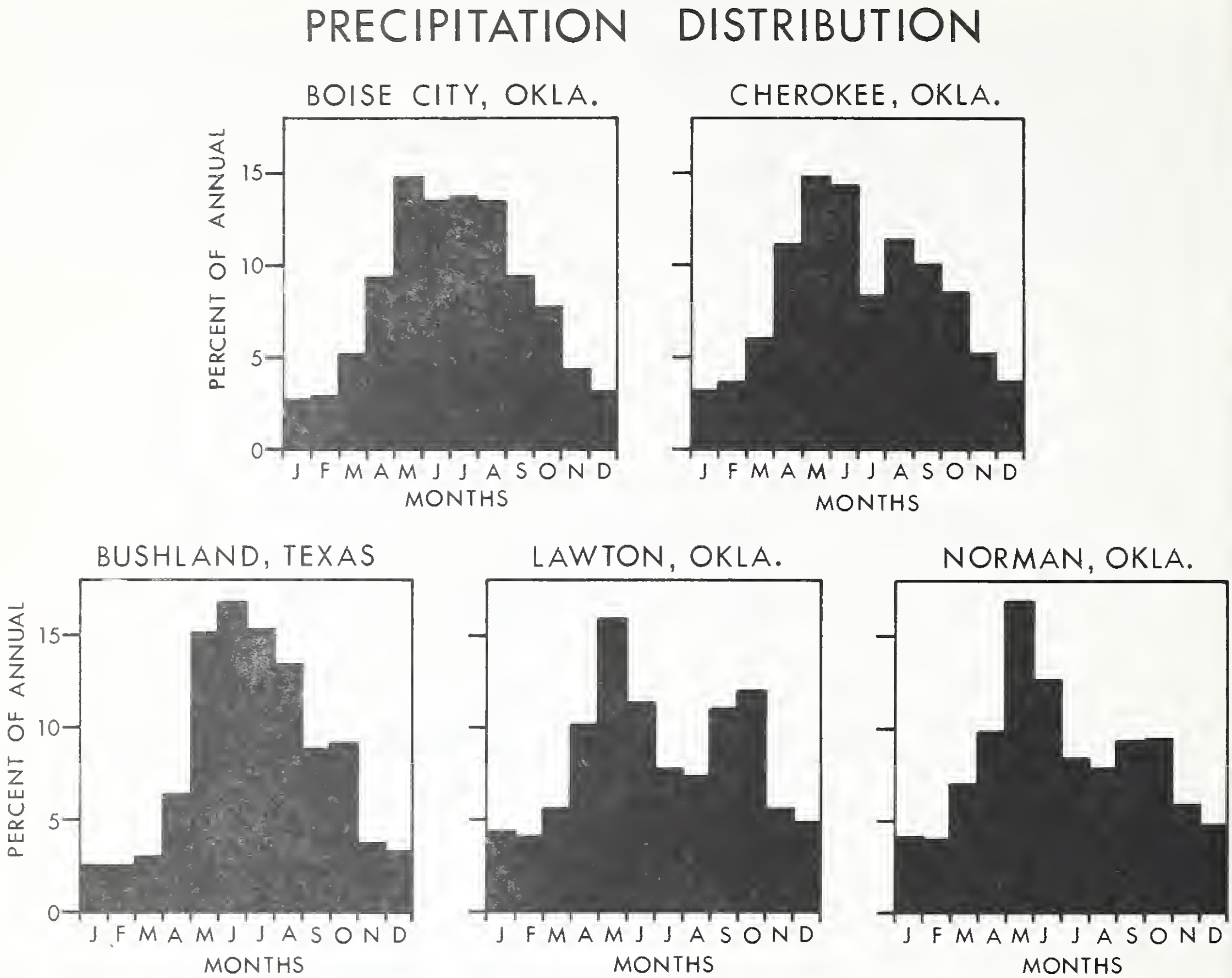


FIGURE 5.6.—Distribution of average monthly precipitation at locations in Texas and Oklahoma.

These experimental results in the Reddish Prairies indicate the contrast in soil properties compared with Bushland in the Texas High Plains. At Bushland, soil water rather than fertility is the limiting factor in dryland wheat production, and stubble-mulch tillage increases rather than decreases wheat yields compared with one-waying. Factors in the yield increase are more available water, a reduction in the straw-grain ratio due to less available nitrogen, and decreased damage from wind erosion.

Although summer fallowing might increase nutrient availability in the Rolling Red Plains and Reddish Prairies, the reasonable price of commercial fertilizer, the serious threat of soil erosion, and the high yields obtained by continuous cropping in this higher rainfall zone are arguments against summer fallowing.

Crops and Cropping Practices

In the southern Great Plains, summer fallowing is used in two systematic cropping systems: (1) Wheat-fallow-wheat, and (2) wheat-sorghum-fallow. It may also be used at irregular intervals when it is desired to change from row crop to small grain on the land in a mixed-farming operation. The time sequences of the harvest, tillage, and seeding operations of the wheat-fallow and wheat-sorghum-fallow systems as they take place in the central Texas Panhandle are as follows:

FIGURE 5.7.—Locations referred to in text.

(A) Wheat-fallow

Time	*Field operations and conditions*
Late June	Wheat harvest
Early July	Initial tillage
July to late September (15 months)	Cultivate fallow
Late September	Plant wheat

(B) Wheat-sorghum-fallow

Time	*Field operations and conditions*
Late September	Plant wheat
October until late June	Growth of wheat
Late June	Wheat harvest
Early July	Initial tillage
July until mid-June	Cultivate fallow
Mid-June	Plant sorghum
Mid-June until Mid-October	Growth of sorghum
Mid-October	Sorghum harvest
Mid-October through April	Uncultivated sorghum stubble
Early May	Initial tillage
May until late September	Cultivate fallow
Late September	Plant wheat

The summer-fallow period in the wheat-fallow system is about 15 months long, extending from wheat harvest near the end of June until wheat is seeded near the end of September of the following year. A wheat crop is harvested in alternate years. The delayed-fallow system can also be used; in this the first cultivation is not made until weed growth begins in the spring of the year—some 10 months after wheat harvest.

In the wheat-sorghum-fallow system, two crops are produced in 3 years, one each of sorghum and wheat. An 11-month fallow period precedes the seeding of each crop. The shorter length of the fallow periods in the wheat-sorghum-fallow system than in the wheat-fallow system might be considered an advantage since water-storage efficiency decreases greatly as the length of time in fallow increases. The time of wheat seeding and the beginning of cultivation of old sorghum land in the wheat-sorghum-fallow system depend somewhat on rainfall.

Water Conservation

Storage Efficiency

Although the main function of summer fallowing is to store water in the soil, its inefficiency in doing so is well known. Mathews and Army (*17*) reported that less than 15 percent of the precipitation was stored by summer fallowing for wheat production in the southern Great Plains and that water-storage efficiency was somewhat higher during the 3-month preparatory period for continuous cropping of winter wheat, from harvest to seeding, when it averaged 22 percent of the precipitation received. This result is understandable since water-storage efficiency is greatest with initially dry soil and decreases as the amount of water in the soil increases.

The voluminous soil-water data from the stubble-mulch plots at Bushland accumulated over 22 years have been summarized in figure 5.10. In this figure, bar graphs show the longtime average available water content of a 6-foot depth of soil at wheat-seeding time. The average available water of subtilled continuous wheat and subtilled wheat on fallow was 4.06 inches compared with 6.07. The extra 2 inches of water on summer-fallowed land was stored over a 12-month period from an average of 18 inches of precipitation. With one-way tillage, average available water for continuous wheat and wheat on fallow was 3.60 compared with 5.02 inches—a difference of only 1.42 inches. For all methods of tillage pooled and for all years, the calculated average efficiency of water conservation during the 3-month preparatory period (harvest to seeding) of continuous wheat was 22 percent of the precipitation, and during the 15 months summer-fallow period for wheat-fallow was 13 percent. This was approximately the same average result reported by Mathews and Army (*17*) for winter wheat in the Great Plains.

Figure 5.10 also shows the high unavailable-water content of the Pullman clay loam soil, which totals 14.4 inches in 6 feet of soil. The amount of unavailable water in this soil always exceeds the amount of available water, even at the conclusion of the summer-fallow period. The term "unavailable water" as used here means water left in the soil when the plant permanently wilts. The amount of unavailable water depends on the type of plant and soil properties, and its determination is based mainly on longtime observation and experience. The largest amount of seeding-time available soil water measured on the stubble-mulch plots was 9 inches on delayed subtilled land in the fall of 1960. This was the wettest year in 20 years.

The high water-holding capacity of the Pullman clay loam at Bushland and of the majority of the wheatland soils in the High Plains is a factor in the poor water-storage efficiency by summer fallowing. Poor water-storage efficiency results from the relatively large amount of water that is held near the surface where it is subject to evaporation between rains. During drought periods, a part of the unavailable as well as the available water can be lost to evaporation and the depth of water loss, contrary to popular opinion, can extend to a depth of 4 or more feet in the soil. Moisture storage during the spring and second summer of the fallow period is difficult. Kuska and Mathews (*13*) stated that soil-water storage at Colby, Kans., did not take place from spring to fall unless precipitation exceeded 15 inches. At Bushland, as much as 18 inches of precipitation has occurred from April 1 to wheat-seeding time without a gain in soil-water content.

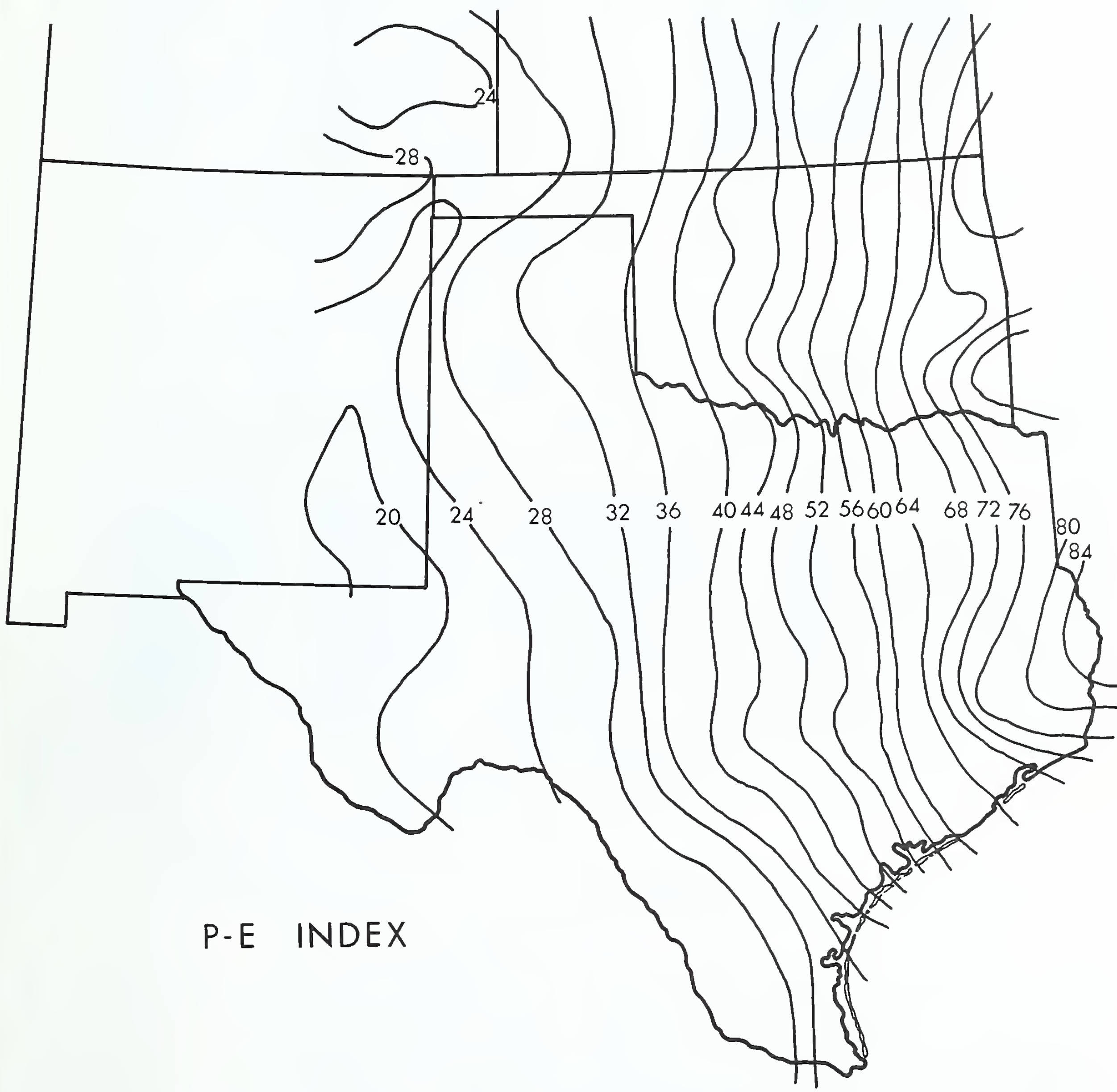


FIGURE 5.8.—Thornthwaite annual P-E index based on 1921–50 average temperature and precipitation (*22*).

Methods of Tillage

Data from the stubble-mulch plots at Bushland afford a comparison of the effect on moisture conservation of tillage with the one-way plow and with a stubble-mulch plow having 30-inch sweeps (fig. 5.10). At wheat-seeding time, on an average, subtilled compared with one-wayed land contained 0.46 and 1.05 inch more available soil water in the case of continuous wheat and wheat on fallow, respectively. Delayed subtilled fallow land was slightly wetter than conventional subtilled fallow land in the upper 4 feet of soil but drier below the 4-foot depth. Although the delayed subtilled fallow land usually becomes thoroughly dried out by weeds from harvest to first frost, it is in a condition to take in water very efficiently from spring

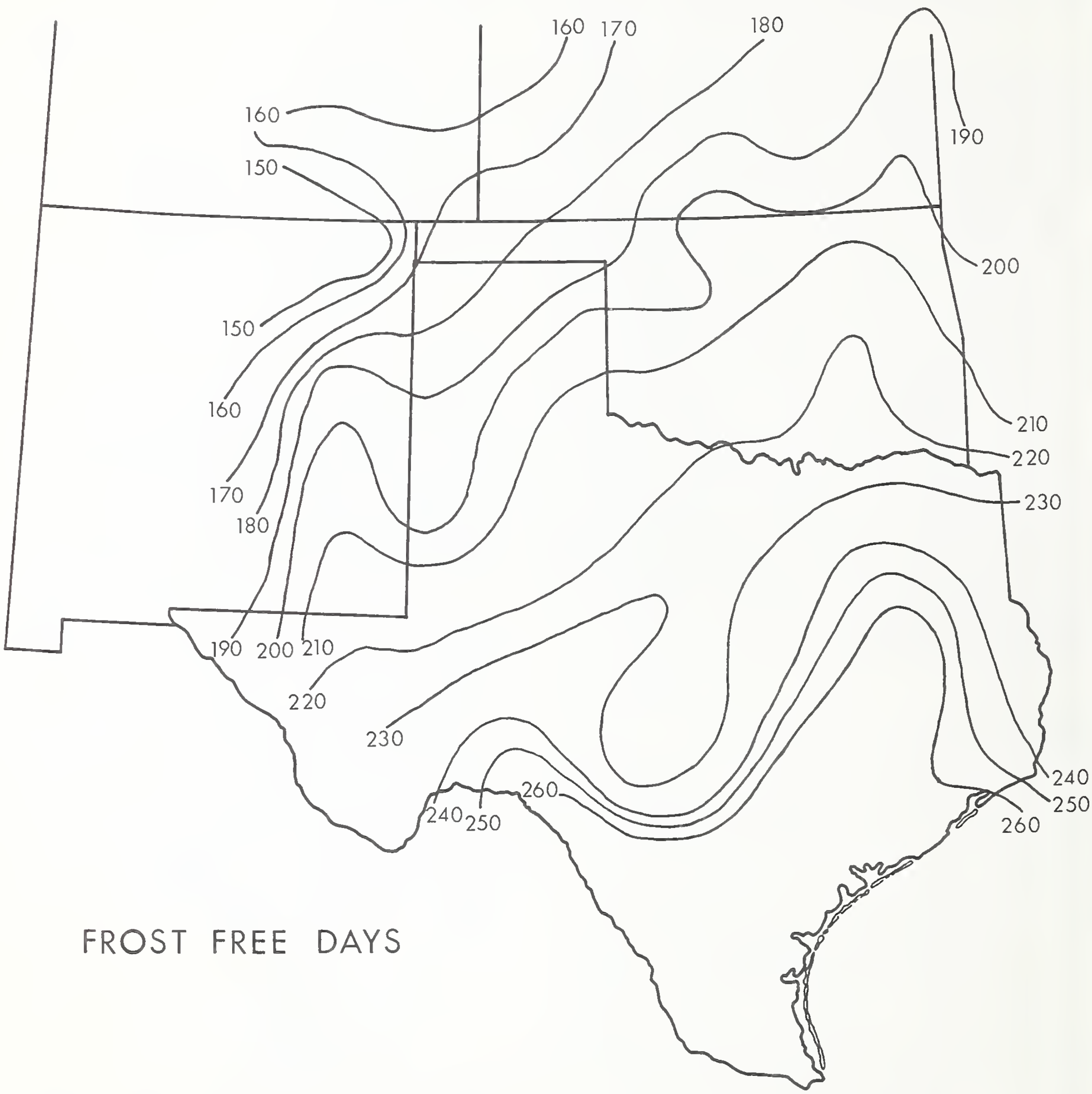


FIGURE 5.9.—Length of average frost-free period (number of days between average date of last occurrence of 32° F. in spring and first occurrence in fall) in the southern Great Plains. (U.S. Weather Bureau data.)

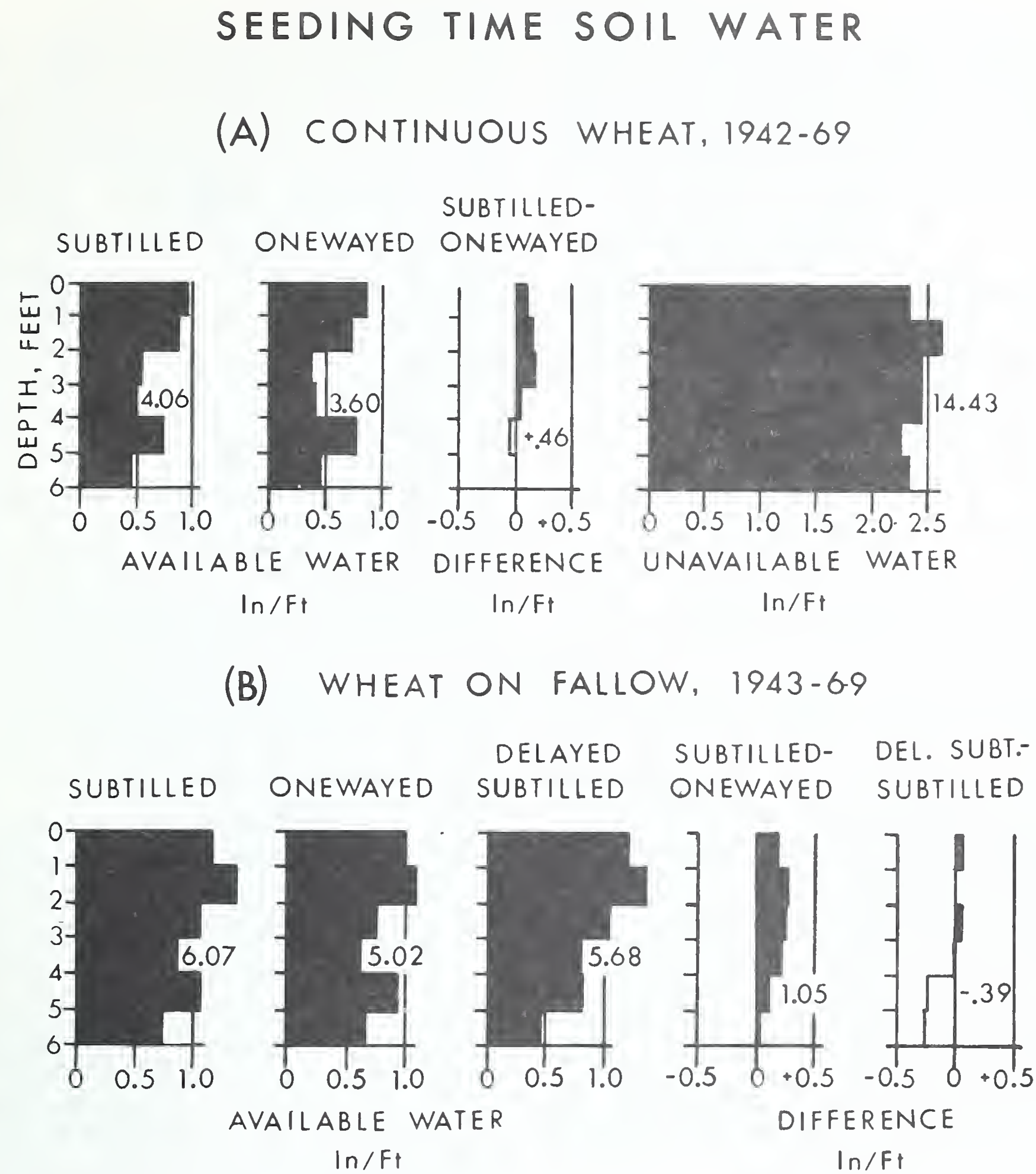


FIGURE 5.10.—Average seeding-time soil-water content. Stubble-mulch plots, USDA Southwestern Great Plains Research Center, Bushland, Tex.: *A*, Continuous wheat, 1942–69; *B*, wheat-fallow, 1943–69.

rains owing to the presence of large drying cracks, old root channels, and an unusually large amount of surface cover. The water deficit due to fall weed growth can be rapidly made up if a good concentration of rains occur before the infiltration of the soil has been reduced by cultivation.

The seeding of wheat in the High Plains frequently must wait until the surface soil is moist enough to get a stand. An accepted procedure is to cultivate as soon as possible after a fall rain and follow up the cultivation with seeding as soon as possible. The cultivation serves to avoid trouble from winter annual weeds. One of the advantages of stubble-mulch tillage, especially delayed subtilled fallow, as compared with clean tillage, is that the mulch causes a slower evaporation rate of soil moisture. The slower evaporation rate lengthens the time after a rain when stands can be obtained.

Erosion

Summer fallowing compared with continuous cropping involves a greater erosion risk. On wheatlands of the High Plains, where the most summer fallowing is practiced, the greatest erosion hazard is from wind during March and April. More than 30 years' experience at Bushland has shown that stubble-mulch tillage is very effective in protecting against wind erosion and should be used routinely in place of clean tillage on summer-fallowed land. Water erosion is not a great hazard (average annual runoff from an instrumented level-terraced field at Bushland, Tex., is only 1 inch per year). However, the surface soils become granular and friable in winter owing to freeze-thaw action, and serious wind erosion can occur. This fact was well publicized during the "dust bowl" days of the 1930's. Since the 1930's, the wind-erosion hazard in the Texas High Plains has been greatly reduced by a large increase in the irrigated acreage. Irrigated acreage in the Texas High Plains has increased about fourfold since 1948, until now about 40 percent of the planted wheat acreage is irrigated. The dryland acreage is interspersed with the irrigated, from which it receives wind-erosion protection. However, because of the depletion of the underground water supply, it has been estimated (*11*) that by the year 2015 the irrigated acreage of the Texas High Plains will be reduced to only 3 or 4 percent of the 1966 acreage. If the predicted decrease in irrigated acreage occurs, the wind-erosion hazard in dryland farming will regain its earlier importance. Guarding against wind erosion is a watchword in crop production involving summer fallowing.

Soil Fertility

Total Nitrogen and Carbon

When a virgin grassland soil is placed in cultivation, a loss in native soil humus begins, which is rapid at first but decreases with time. Both carbon and nitrogen are lost from the soil humus, but carbon is lost more rapidly than nitrogen. As a result, the carbon-nitrogen ratio of the soil decreases with time in cultivation. The rate of organic-matter loss depends on the manner in which soil is farmed and on the nature of the soil and climate. Row cropping is recognized as causing a more rapid loss of organic matter than small-grain farming. Similarly, summer fallowing causes a more rapid organic-matter loss than continuous cropping. Theoretically, the more rapid the initial loss of organic matter, the lower the equilibrium level reached when annual additions just balance annual losses of organic matter. Earlier data suggested that an equilibrium level of organic matter in Great Plains soils would be reached after approximately 75 to 100 years in cultivation (*8*). Hobbs and Thompson (*10*) reported that at Hays, Kans., land in continuous sorghum or sorghum-fallow from 1916 to 1958 when later farmed less intensively for 8 years by the wheat-sorghum-fallow system increased in nitrogen content. This indicated that 42 years of row cropping had reduced the soil nitrogen content below the equilibrium level for wheat-sorghum-fallow. It is desirable to maintain the organic matter at as high a level as possible because it has a beneficial effect on the physical condition of the soil and because it is a source of plant nutrients.

Figure 5.11 illustrates the course of the decline of organic matter on the stubble-mulch plots at Bushland from 1941 to 1966. This Pullman clay loam soil was first placed in cultivation in 1927. From an initial organic-matter content of 2.44 percent in the 0- to 6-inch soil layer in 1941, the average organic-matter content of stubble-mulch plots had fallen to 1.62 and 1.79 percent for the wheat-fallow and continuous wheat, respectively, by 1966 (*12, 25*). One-way tillage resulted in a more rapid loss of organic matter than stubble-mulch tillage, and the wheat-fallow system caused a more rapid loss than continuous cropping. The loss of organic matter was slowest on the delayed subtilled fallow plots, because of fewer cultivations, extra addition of organic matter from weeds, and possibly to greater shading of the soil. Unger (*25*) reported that in 1966 the amount of total nitrogen in the soil was closely correlated with the organic-matter content.

From a soil-conservation standpoint, it would be concluded that delayed subtilled fallowing is more desirable than either conventional summer fallowing

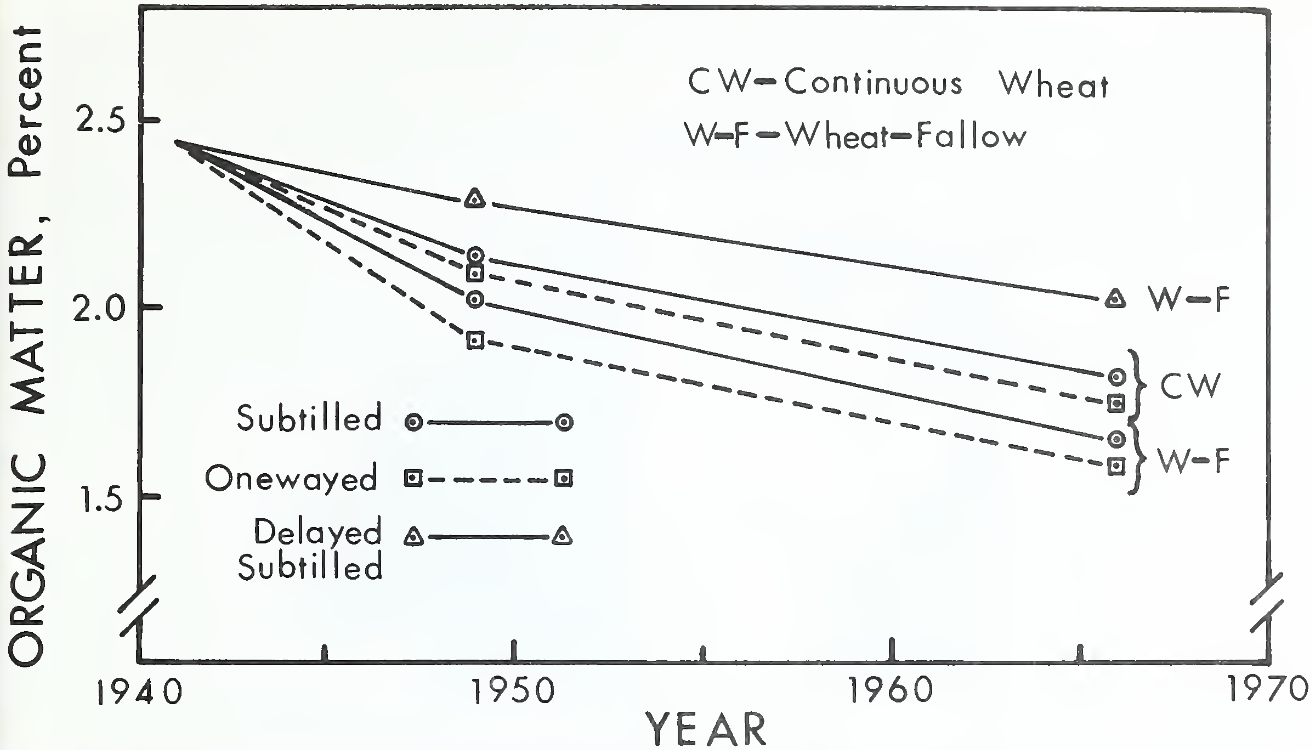


FIGURE 5.11.—Organic-matter content, 0–6 inches, of stubble-mulch plots at Bushland, Tex., in 1941, 1949, and 1966 as related to cropping system and tillage method (*12*, *24*).

or continuous cropping to wheat. As has been mentioned, the reason delayed summer fallowing is not used to any extent in raising wheat in the southern Great Plains is because of the large amount of weed seed produced, especially in wet years.

Nitrate Nitrogen

More complete incorporation of plant residue with the surface soil, such as with one way tillage (inversion-type) compared with subtillage by sweeps (noninversion type) accelerates the decomposition of plant material with subsequent release of nitrate-nitrogen. Over the years, the nitrate content of the one-wayed plots at Bushland has been higher than that of the subtilled plots, and the nitrate content of the wheat-fallow plots has been higher than that of the continuous wheat plots. Nitrate-nitrogen content has been consistently lowest in the soil of the delayed subtilled fallow plots. Figure 5.12 summarizes the results of soil nitrate analyses of the plots in the fall of 1970. The analyses show the longtime effects of the different tillage and management methods used. The total amount of nitrate-nitrogen per acre per 6 feet of soil ranged from 78 pounds in the delayed fallow plots to 462 pounds in the one-wayed fallow plots. The amounts of nitrate-nitrogen, as would be expected, were proportional to the rates of decrease of organic matter (fig. 5.11).

The high natural nitrogen fertility of this typical High Plains soil can be realized from the fact that the 462 pounds/acre of nitrate-nitrogen of the one-wayed fallow plots is equivalent to the amount of nitrogen that would be removed in the wheat harvested over a period of about 45 years.

Crop Yields

Because soil and climatic conditions at the Southwestern Great Plains Research Center, Bushland, Tex., are recognized as being typical of a major part of the High Plains area where summer fallowing is of the greatest importance, results obtained at that center will be given the most attention in the following discussion. Results obtained at the Lawton and Woodward, Okla., field stations in the Red Rolling Plains and at the Texas Agricultural

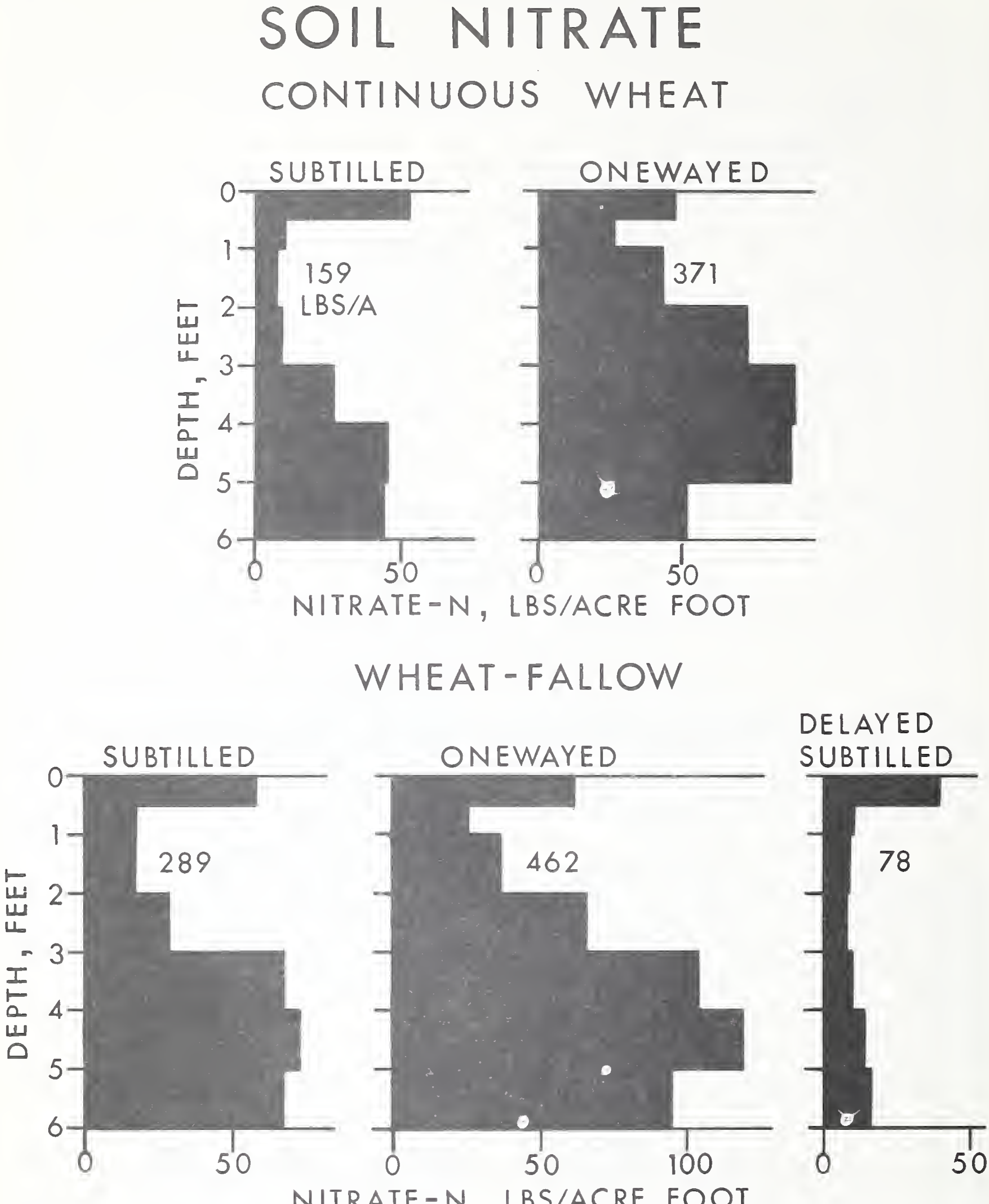


FIGURE 5.12.—Average nitrate-nitrogen content of 1-foot layers of soil of stubble-mulch plots after 28 years with different management and tillage treatments. Total pounds per acre of nitrate-nitrogen stated numerically.

Experiment Station No. 6 at Denton, in the Grand Prairie land resource area, will also be discussed.

High Plains Area, Bushland, Texas

The stubble-mulch plots at Bushland were established in 1941. Continuous wheat, wheat-fallow, and wheat-delayed fallow systems have been used on the plots. Two types of tillage have been used—one-waying and subtilling (table 5.1).

The average yield combining all tillage methods was 15.0 bushels/acre for wheat-fallow and 9.6 bushels/acre for continuous wheat. The yield increase due to fallowing compared with continuous cropping was, therefore, 56 percent. This was less than the 100 percent yield increase that would be needed if a given acreage farmed in the wheat-fallow system were to give as much production as if continuously cropped. Yield increases approaching 100 percent have been reported from experiment stations in western Kansas and Nebraska and in northeastern Colorado (*21*). This indicates that summer fallowing to increase yields in the High Plains of Texas and Oklahoma is relatively inefficient compared with the central Great Plains.

Table 5.1.—*Yields of wheat on fallow and of continuous wheat as related to tillage, stubble-mulch plots, Southwestern Great Plains Research Center, 1942–70*

Year	Continuous wheat		Wheat on fallow		
	One-wayed	Subtilled	One-wayed	Subtilled	Delayed subtilled
	Bu./A.	*Bu./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*
1942	20.1	19.0			
1943	6.0	7.1	11.9	14.6	12.9
1944	24.5	26.4	28.4	28.4	30.3
1945	6.3	6.9	16.7	20.4	23.3
1946	2.6	6.0	8.5	13.9	15.4
1947	28.4	34.3	33.1	36.8	36.2
1948	4.6	6.2	13.9	15.7	15.6
1949	21.5	19.4	36.0	38.4	36.1
1950	0	0	0	0	0
1951	7.4	8.6	9.1	13.0	10.8
1952	4.1	5.4	16.0	17.4	16.8
1953	.4	.6	1.9	2.8	2.8
1954	8.4	14.2	14.3	18.4	19.8
1955	0	0	0	0	0
1956	0	0	0	0	0
1957	0	0	0	0	0
1958	14.3	14.9	15.7	15.8	13.8
1959	16.8	24.9	20.1	30.5	29.0
1960	19.2	19.5	22.9	24.1	22.6
1961	8.3	8.4	11.3	12.5	12.4
1962	.4	.6	4.7	7.1	6.1
1963	7.5	8.2	7.4	10.5	11.9
1964	11.5	14.2	16.5	15.6	18.4
1965	3.6	3.7	4.1	4.0	3.6
1966	7.8	12.4	14.7	17.2	19.0
1967	7.0	8.0	21.0	17.1	12.8
1968	12.4	10.7	18.6	18.3	16.0
1969	12.6	13.7	27.0	30.3	30.1
1970	11.0	13.2	19.1	17.5	16.9
Average	8.8	10.3	14.0	15.7	15.4
Average for management system	9.6			15.0	

Although summer fallowing is not efficient in storing water, raising wheat may not be feasible in the driest part of the High Plains much of the time, except by summer fallowing. However, as Mathews (*16*) noted, in going from east to west, or from a wetter to a drier climate, by the time a sufficiently high percentage yield increase is obtained to make production by summer fallowing a "must" (as at Tucumcari, N. Mex.), yields have become so low and failures so frequent that raising dryland wheat is not justified.

Not only are the high density, low permeability, and high water-holding capacity of the Pullman clay loam soil at Bushland unfavorable for efficient water conservation by summer fallowing but also climatic factors contribute to the low efficiency of summer fallowing. The climatic aspect of low fallow efficiency is illustrated in table 5.2, which compares conditions at Kimball, Nebr., in an area well suited for summer fallowing, especially for delayed summer fallowing, with conditions at Bushland. The Precipitation-Effectiveness Indices for the two locations are the same.

Due to a combination of higher latitude and elevation, the frost-free period is nearly 2 months shorter at Kimball than at Bushland. The shorter frost-free period and approximately one-third lower annual pan evaporation indicate that there would be a lower evaporation loss at Kimball. The preparatory period for continuous cropping of wheat is about a month shorter at Kimball—52 days compared with 82 days at Bushland. At Kimball at wheat-seeding time, nitrogen may still be tied up in an unavailable form in the decay process of the straw from the previous crop. This causes a nitrogen-deficiency problem with continuous cropping that does not occur at Bushland.

Factors related to the greater success of delayed summer fallowing at Kimball than at Bushland are the 7-week shorter weed-growing period from harvest to first freeze, and the three times larger amount of snow received.

On Bushland plots, the average yield of wheat on delayed subtilled fallow land, 15.4 bushels/acre, was virtually the same as that on conventional subtilled fallow land, 15.7 bushels/acre. Although delayed fallowing requires 30 percent fewer cultivations than summer fallowing as ordinarily practiced, produces as well, and is more desirable from the soil-conservation standpoint, it is not used much in the southern Great Plains. This is probably because of the long harvest-to-first-frost weed-growing period and the large amounts of weed seed produced in some years.

TABLE 5.2.—*A comparison of factors related to summer-fallow efficiency at Kimball, Nebr., and Bushland, Tex.*

Location	Average starting date for [1]		Harvest to seeding	Average [2] annual precipitation	Average annual snow	Snow [3] as percentage of annual precipitation
	Harvesting	Seeding				
			Days	*Inches*	*Inches*	
Kimball	July 11	Sept. 1	52	17.35	40	23
Bushland	June 21	Sept. 11	82	19.67	13	7

Location	Date of 32° F.[2]		Frost-free days	Wheat harvest to first fall 32° [2]	P-E Index [4]	Annual pan evaporation [5]	Elevation, m.s.l.
	Last spring	First fall					
				Days		*Inches*	*Feet*
Kimball	May 14	Sept. 27	135	78	33.9	65	4,700
Bushland	Apr. 19	Nov. 1	194	129	33.6	95	3,800

[1] From (*15*).
[2] Precipitation and temperature, U.S. Weather Bureau data, 1921–50.
[3] Assuming 10 inches snow equals 1 inch water.
[4] Based on 1921–50 precipitation and temperature normals (*22*).
[5] From figure 1.4, p. 9.

Curves were fitted (*6*, *18*, *20*) to the yield data of table 5.1 and are shown in figure 5.13. Values of a few selected points on the probability curves of figure 5.13 are given in table 5.3. For example, table 5.3 shows that the yield that will be exceeded 25 percent of the time with continuous cropping of wheat is 14.9 bushels/acre if subtillage is used and 12.7 bushels/acre if one-way tillage is used. Yields tend to be higher with subtillage than with one-way tillage at Bushland.

In a second experiment at Bushland, yields of wheat in the continuous wheat, wheat-fallow, and wheat-sorghum-fallow systems were compared for 12 years. Average yields from this experiment are given in table 5.4.

The yield increase due to summer fallowing compared with continuous cropping of wheat averaged 41 percent. Wheat after fallow yielded 1.7 bushels/acre less in the wheat-sorghum-fallow than in the wheat-fallow system. The most grain per 3-year period was produced by the wheat-sorghum-fallow system.

Rolling Red Plains, Lawton, Oklahoma

Yields of continuous wheat and wheat-fallow obtained at the Lawton Field Station during a 26-year period, 1924–49, were reported by Osborn and Mathews (*19*). Their publication can be consulted for yields by individual years. The soil on this station is Lawton silt loam (fine, mixed, thermic Udic Argiustoll). Gamma-distribution curves fitted to the Lawton data are shown in figure 5.14. From the fitted curves, yields related to certain yield probabilities have been taken and are given in table 5.5.

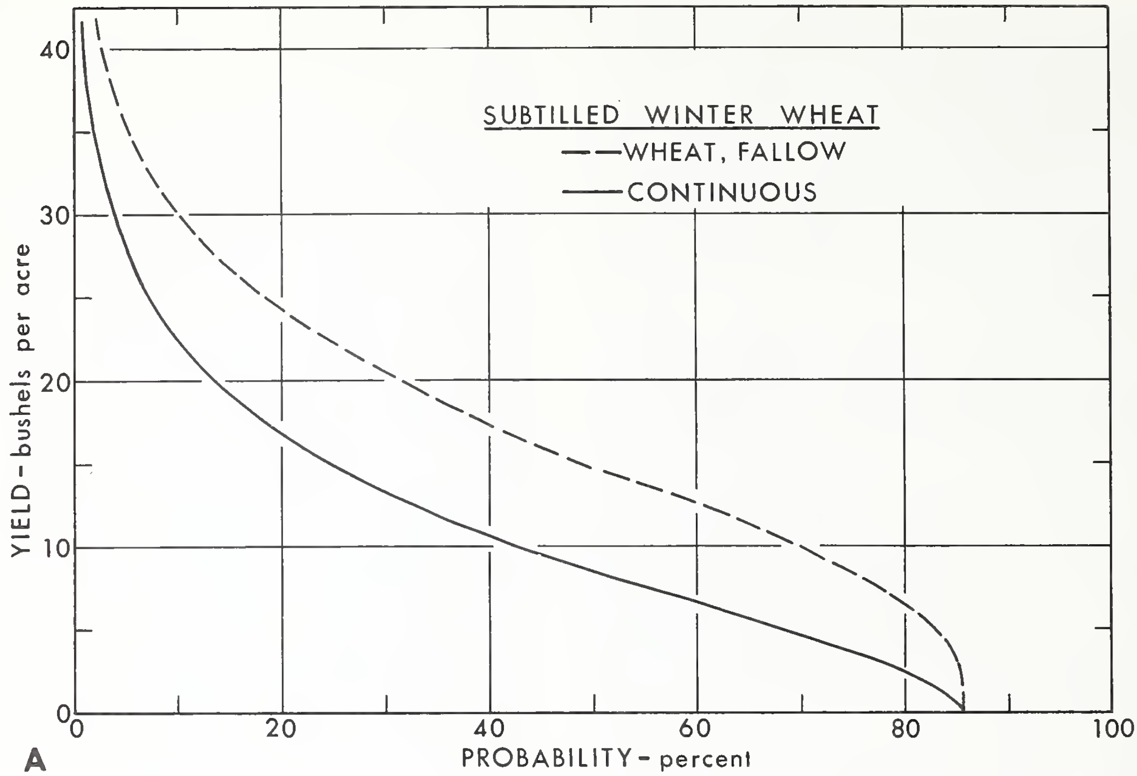
The average yields of continuous wheat and wheat-fallow at Lawton without the use of manure were 15.8 and 19.4 bushels/acre, respectively. This was a wheat-fallow:continuous wheat yield ratio of 1.23, which is even lower than the 1.56 obtained at Bushland. Osborn and Mathews (*19*) considered soil erosion to be of serious concern at Lawton and regarded summer fallowing for wheat production in the Lawton area to be justified only to produce seed wheat of high purity or to rotate wheat with a summer-rilled row crop. By 1949, it was considered that fertility rather than moisture had become the limiting factor in crop production.

A yield response to manuring in the wheat-fallow sequence was obtained at Lawton from 1924–49. The average yields were 21.3 and 19.4 bushels/acre for manured and unmanured wheat-fallow, respectively. This was not a large response to manuring, but the response was increasing with time and undoubtedly would be much greater today. In another experiment at Lawton, yields of continuous wheat with and without manuring were compared from 1924–49; listing was the tillage method used. Yields were decreased by manuring during the first half of the experiment and then were increased by manuring during the latter half of the experiment. This again showed the increasing fertility deficit with time. The precipitation at Lawton during the 1924–49 period averaged 28.7 inches per year. Before 1949, the principal fertility need of the soil was shown to be phosphorus.

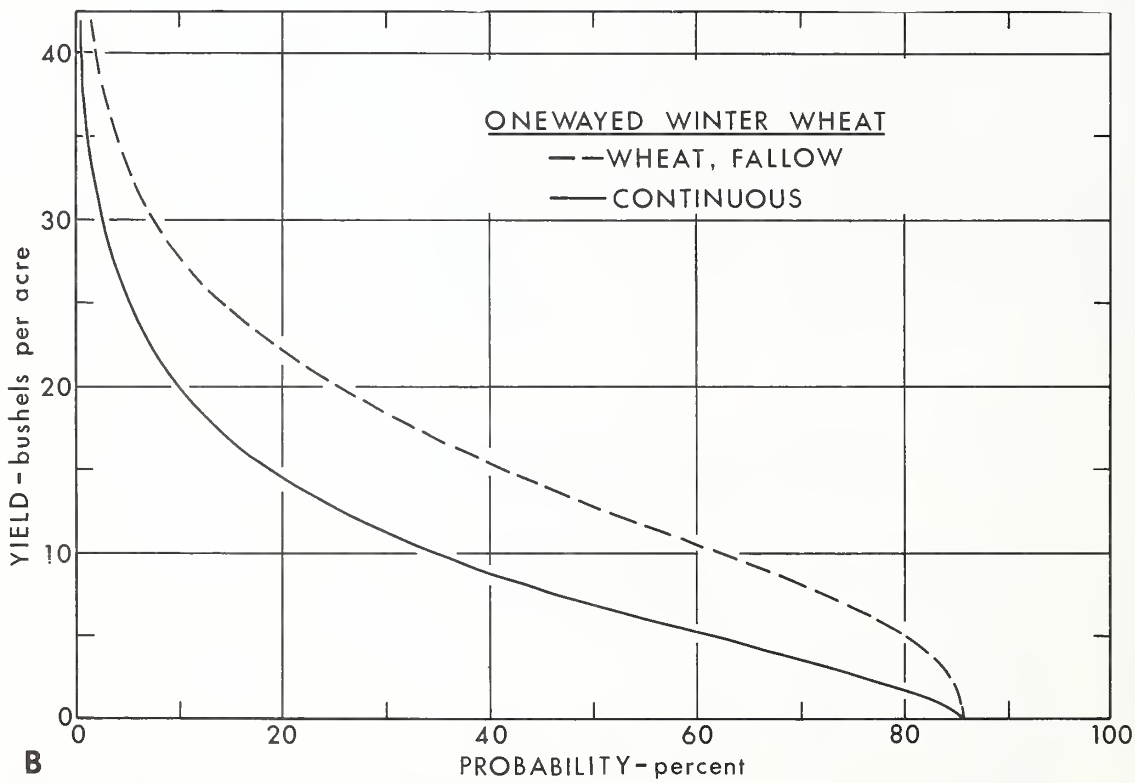
Lawton is an example of a situation where fertility rather than water limits wheat yields and where a commercial fertilizer, possibly supplemented with manure, would be a more economical way of supply-

TABLE 5.3.—*Yields associated with stated levels of probability for combination of tillage method and cropping system, Bushland, Tex., 1943–70*

Cropping system and tillage method	Probability that yield will be greater than indicated level (bushels per acre) for percent of years—						
	5	10	15	25	50	75	80
Continuous wheat:							
Subtilled	27.6	22.3	19.2	14.9	8.3	3.4	2.3
One-wayed	25.0	20.0	16.7	12.7	6.8	2.5	1.7
Wheat-fallow:							
Subtilled	35.4	30.2	26.7	22.1	14.6	8.2	6.3
One-wayed	33.2	27.6	24.6	20.1	12.8	6.6	5.0



A



B

FIGURE 5.13.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems on stubble-mulch plots at the Southwestern Great Plains Research Center, Bushland, Tex., 1943–70: *A*, Subtilled; *B*, onewayed.

ing fertility needs, and more conserving of the soil, than summer fallowing.

Rolling Red Plains, Woodward, Oklahoma

The soil at the Woodward Field Station is Pratt fine sandy loam (sandy, mixed, thermic Psammentic Haplustalfa). Wheat yields over a 34-year period averaged 22.2 bushels/acre for wheat-fallow and 17.3 bushels/acre for continuous wheat (*14*). Yields were increased only 28 percent by summer fallowing compared with continuous cropping (just half the percentage increase obtained on the stubble-mulch plots at Bushland).

Wheat at Woodward is a reliable crop, and summer fallowing does not increase its reliability. Fallowing serves mainly to increase yields in years of fair to high production rather than reduce the risk of crop failure, as can be seen from the curves of figure 5.15. Fallowing is not considered to be a cropping practice that is well adapted to the Woodward area; but rather, one to be avoided because of the greater loss of soil nitrogen and carbon that it causes. Table 5.6 gives the yields for certain probability levels at Woodward.

TABLE 5.4—*Average yields of wheat and sorghum in continuous wheat, wheat-sorghum-fallow, and wheat-fallow cropping systems; and total grain produced per 3 years, Bushland, Tex., 1958–69*

Cropping system	Average yield per crop		Average grain produced per 3 years
	Wheat	Sorghum	
	Bu./A.	*Lb./A.*	*Lb./A.*
Continuous wheat	10.4	---------	1,870
Wheat-sorghum-fallow	13.0	1,550	2,330
Wheat-fallow	14.7	---------	1,320

Grand Prairie, Denton Texas

The soil at Substation No. 6 is San Saba clay (fine, montmorillonitic, thermic, shallow, Udic Pellusterts).

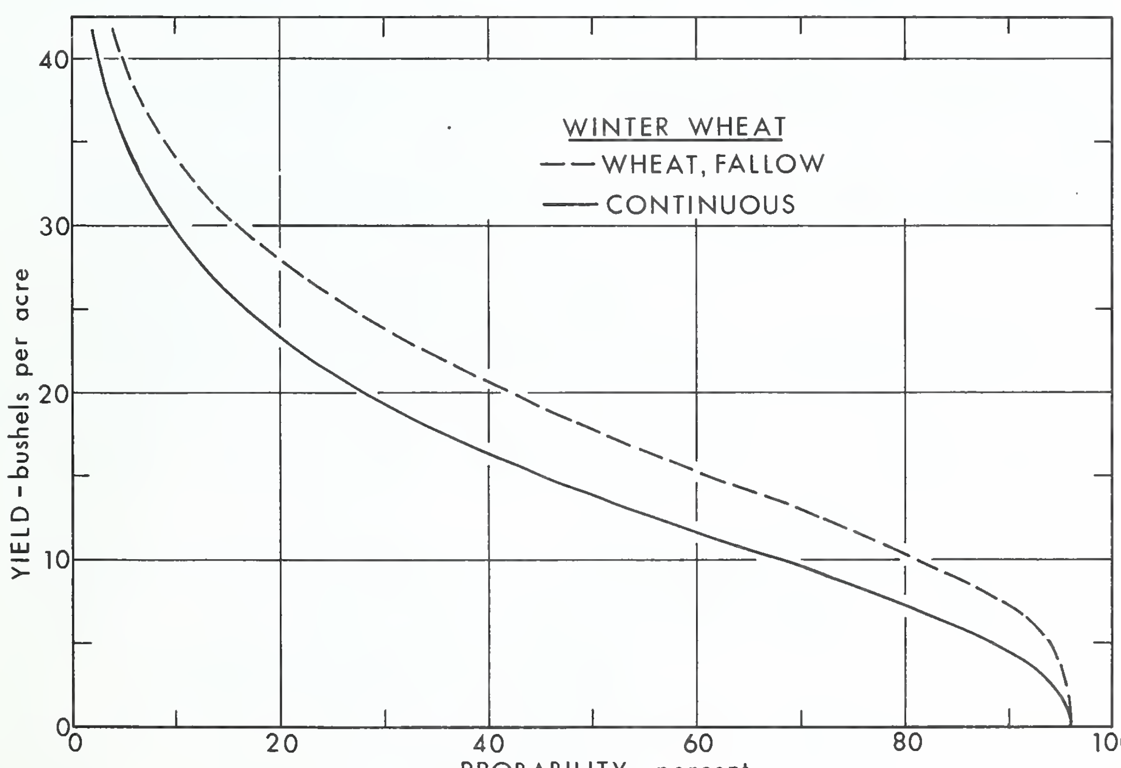


FIGURE 5.14.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping system at Lawton Field Station, Lawton, Okla., 1924–49.

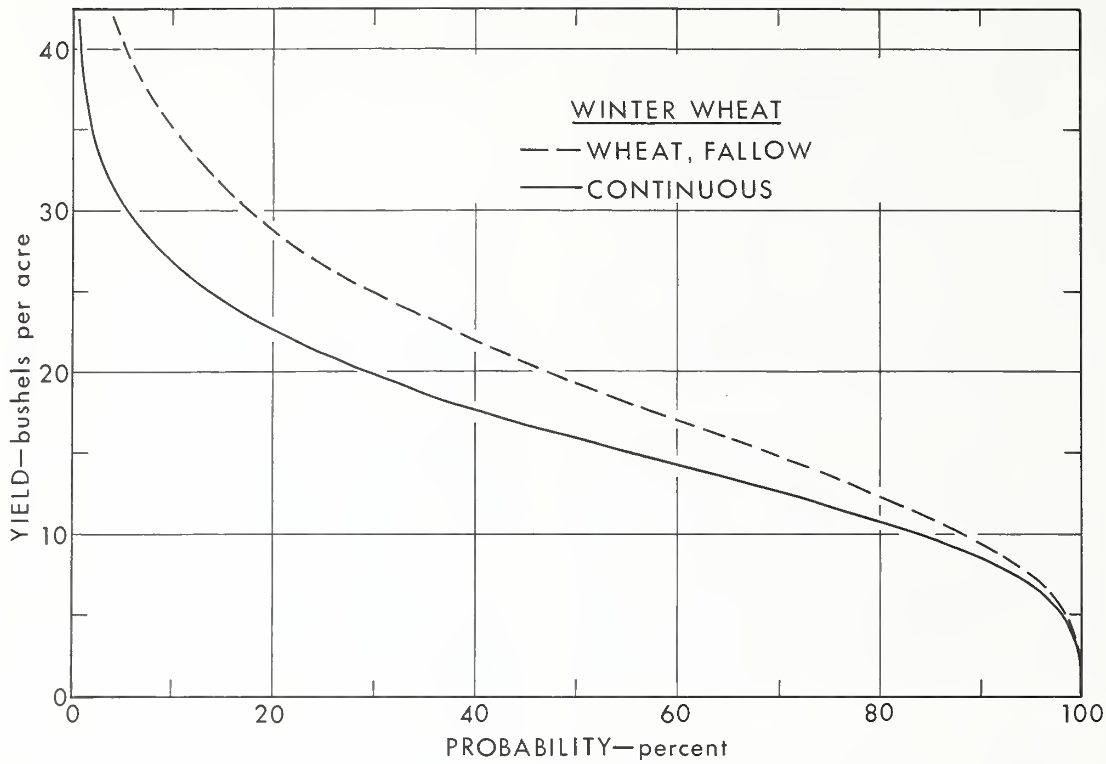


FIGURE 5.15.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at Woodward Field Station, Woodward, Okla., 1915–48.

TABLE 5.5.—*Yields associated with stated levels of probability for continuous wheat and wheat-fallow, Lawton Field Station, 1924–49*

Cropping system	Probability that yield will be greater than indicated level (bushels per acre) for percent of years—						
	5	10	15	25	50	75	90
Continuous wheat	35.8	29.8	26.0	21.2	13.9	9.5	4.4
Wheat-fallow	40.1	34.0	30.6	25.8	17.8	11.7	7.1

TABLE 5.6.—*Yields associated with stated levels of probability for continuous wheat and wheat-fallow, Woodward Field Station, 1915–48*

Cropping system	Probability that yield will be greater than indicated level (bushels per acre) for percent of years—						
	5	10	15	25	50	75	90
Continuous wheat	30.7	26.8	24.4	21.2	16.0	11.6	8.4
Wheat-fallow	40.5	35.2	31.6	26.4	19.2	13.6	9.3

Yield data from two experiments at Denton comparing continuous wheat and wheat-fallow are given in table 5.7. Although yields were somewhat higher in the rotation studies than in the fallow-fertility experiment, both experiments showed that with adequate fertilization continuous wheat yielded as much as wheat on fallowed land. There would be therefore no possible economic justification for summer fallowing at Denton from the standpoint of the amount of grain raised. Wheat in the Grand Prairie land resource area is used mainly for grazing.

Summary and Conclusions

Most of the dryland wheat acreage in the southern Great Plains is in the High Plains, Reddish Prairies, and Rolling Red Plains land resource areas. A smaller acreage is in the Grand Prairie. Most of the dryland wheat raised by summer fallowing is in the High Plains land resource area, in the Texas and Oklahoma Panhandles, and in eastern New Mexico. About 50 percent of the dryland wheat was raised on summer-fallowed land in the western half of the Texas Panhandle during 1968–70.

There is a steep east-west gradient in annual precipitation—ranging, at the latitude of the Texas Panhandle, from 35 inches at the eastern boundary of the Reddish Prairie to 16 inches in eastern New Mexico. The east-west decrease in precipitation is partially compensated for by the increase in elevation of 1,000 to 1,300 feet per 100 miles, which causes lower temperatures and a shorter frost-free period (10–13 days/100 miles).

The High Plains soils on which most of the dryland wheat is raised have gentle slopes on which water erosion is less of a problem than wind erosion. The soils are derived from Tertiary materials and have a high natural fertility. In this area, the benefit derived from summer fallowing is primarily from the storage of water. Water, rather than fertility, tends to limit wheat production.

The soils of the Rolling Red Plains and Reddish Prairies are derived mainly from Permian materials and tend to be highly erodible. They have a more limited fertility than the High Plains soils. In these land resource areas, wheat yields are increased so little by summer fallowing and the erosion hazard is so great that summer fallowing should be avoided.

In the Grand Prairie, if fertilizer is used, wheat yields are as high with continuous cropping as with summer fallowing.

The yield increase due to summer fallowing in the central Texas Panhandle compared with continuous cropping is about 50 percent. This is somewhat less than the 100 percent increase reported farther north where summer fallowing is more adapted. The poor efficiency of summer fallowing in the High Plains is due to the fine texture and associated low permeability of the soil, and to the high evaporation rate. The longtime average moisture-storage efficiency by fallowing at Bushland, Tex., was only 22 percent of the precipitation stored as soil water

TABLE 5.7.—*Comparison of average yields of continuous wheat and wheat-fallow as affected by N and P fertilization in 2 experiments, Denton, Tex., 1964–67 and 1963–66* [1]

Experiment and date	Fertilization	Yield: Continuous wheat	Yield: Wheat-fallow
		Bu./A.	*Bu./A.*
Rotation studies (1964–67)	Check	23.4	36.5
	40–40–0	33.0	33.5
	Check	18.0	21.4
Fallow-fertilization (1963–66)	0–40–0	20.8	23.8
	40–40–0	26.1	23.1
	40–0–0	23.1	21.1

[1] From unpublished data of P. A. Rich (research associate, North Central Texas Research Station, Denton, Texas).

for the 3-month preparatory period of continuous wheat and 13 percent for the 15-month period for wheat-fallow.

Summer fallowing has the disadvantage of exposing the soil to a relatively high wind-erosion risk and of causing an accelerated loss of soil nitrogen and carbon.

Reasons for the use of summer fallowing in the High Plains area are that it decreases the risk of crop failure, increases the acreage that can be handled with a limited amount of labor and equipment, decreases the per-bushel harvesting cost, affords a way of going from row crop to small grain, aids in combating certain insect pests and insect-carried diseases, and aids in producing high-purity seed. There is also an intangible value to the farmer from being able to seed a crop with improved prospects for obtaining a good stand and obtaining a yield worth harvesting. Summer fallowing to control winter annual weeds is seldom necessary in the southern Great Plains.

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CHAPTER 6.—SUMMER FALLOW IN THE NORTHWEST[1]

G. E. Leggett, R. E. Ramig, L. C. Johnson, and T. W. Massee [2]

Introduction

The principal dry-farmed area in the Northwest lies east of the Cascade Mountains in Oregon and Washington and extends into northern Idaho. This area includes the Columbia Plateau and the Palouse and Nez-Perce Prairies major land resource areas (fig. 6.1). A review of the agriculture within this area was given by Horner and others (*14*). Smaller but significant dry-farmed areas are in some of the mountain valleys of the Blue Mountains of eastern Oregon and Washington, and across southern Idaho. Another large contiguous dry-farmed area, the Eastern Idaho Plateaus major land resource area, is located in southeastern Idaho (fig. 6.1). Early settlers in the Columbia Plateau and Palouse and Nez-Perce Prairies attempted to dry-farm the land in the 1880's by producing a crop each year, but the yields were so low that alternate cropping and summer fallow soon became the general practice where annual precipitation was 18 inches or less (*19*).

Today, summer fallowing is practiced generally in areas receiving less than 13 inches of annual precipitation; areas receiving from 13 to 16 inches are considered a transition zone. Areas receiving more than 16 inches of precipitation annually generally do not require the use of summer fallow for successful crop production, although some fallowing is done in these areas as farmers adjust their operations to the national farm programs.

This section summarizes available information regarding summer fallow in the Northwest and presents the advantages and disadvantages of fallowing with regard to crop yield and soil and water conservation.

Climate

Annual precipitation in the Northwest ranges from 6 to more than 140 inches (fig. 6.2). However, in the small grain farming areas, annual precipitation ranges from 8 to 30 inches and the climate is classified as semiarid to subhumid, microthermal, and deficient in rainfall in the summer. Average annual temperatures in these areas range from 38 to 55° F., and the frost-free season ranges from 80 to 200 days, except in the mountain valleys where it is shorter.

The climate of Washington, Oregon, and the Idaho panhandle is determined primarily by prevailing westerly winds from the cyclonic storms that sweep in from the Pacific Ocean. Here, winters are cool and moist, and 70 percent of the annual precipitation occurs in the 6-month period November to April. Winter temperatures are usually mild, and depth of frost varies from a few to about 30 inches. Summers are hot and dry. Rainfall is least at the lower elevations on the lee side of the Cascade Mountains, and increases as land elevation increases eastward with approach to the Blue Mountains.

In southeastern Idaho, the climate is transitional between the maritime climate of the Pacific coast and that of the Great Plains. Precipitation on the high plateaus (4,500–6,500 feet above sea level) in southeastern Idaho and northern Utah ranges from 12 to 20 inches per year. The distribution is about 1 inch per month for all months except May and June, when summer thunderstorms increase the monthly precipitation up to about 1.5 to 2 inches (fig. 6.3). The soil is snow-covered and frozen during most of the winter.

[1] Contribution from the Agricultural Research Service, USDA, in cooperation with the Agricultural Experiment Stations of Idaho, Oregon, Utah, and Washington.

[2] Soil scientists, Western Region, ARS, Snake River Conservation Research Center, Kimberly, Idaho; Columbia Plateau Conservation Research Center, Pendleton, Oregon; Palouse Conservation Field Station, Pullman, Wash.; and Snake River Conservation Research Center, Kimberly, Idaho, respectively.

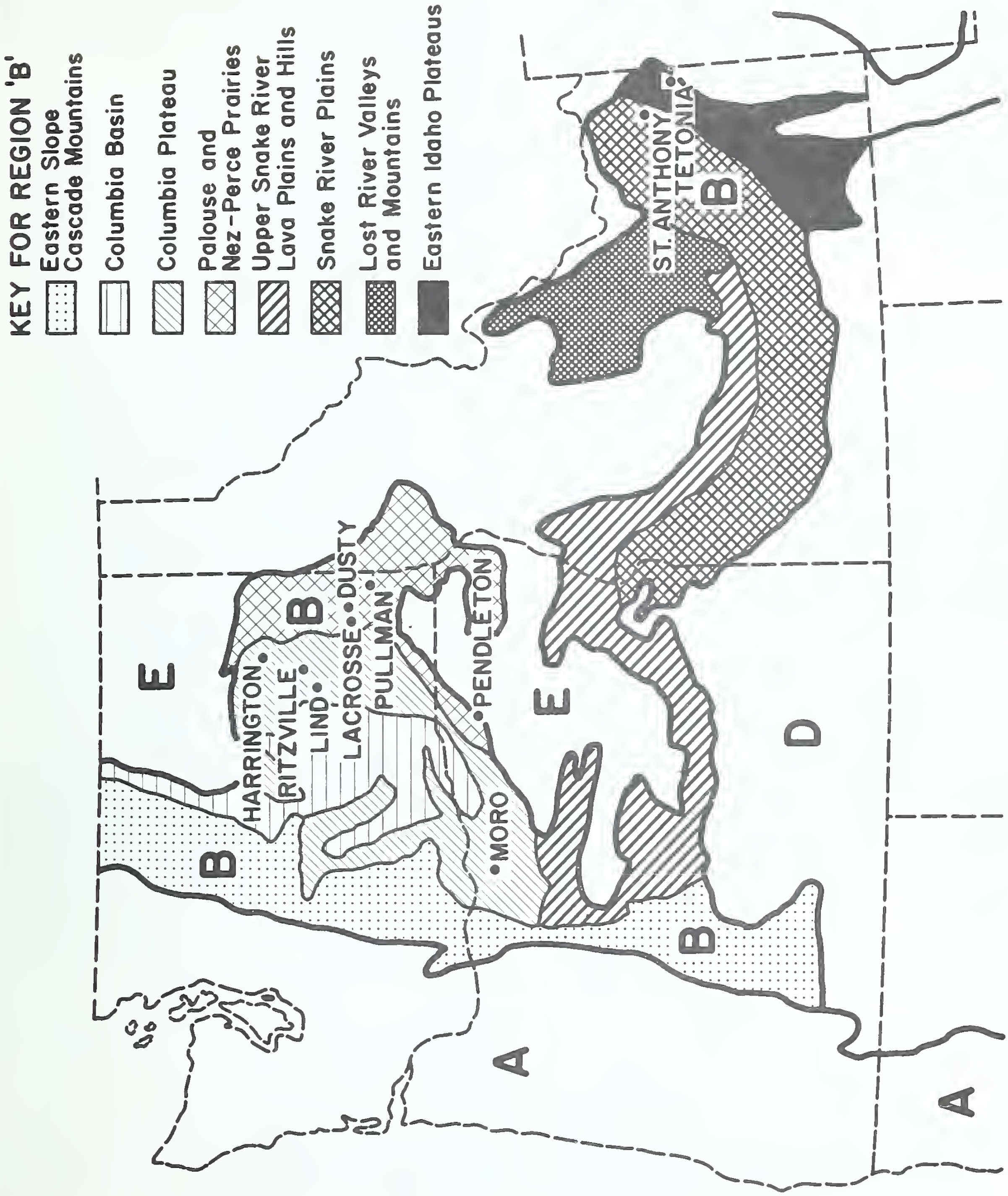


FIGURE 6.1.—Land resources regions and major land resource areas (and locations referred to in text) in the Northwest (*1*).

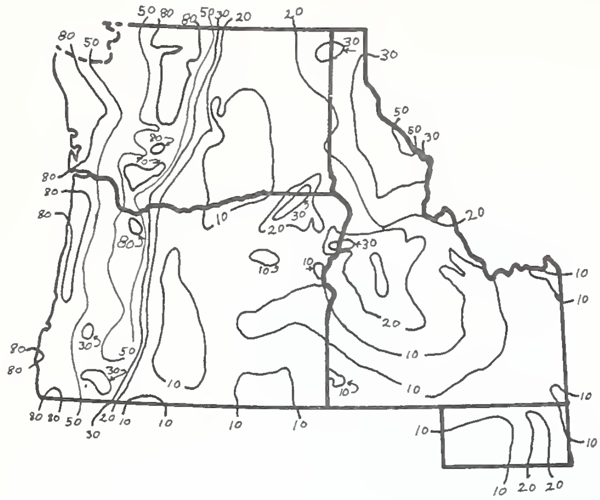


FIGURE 6.2.—Mean annual precipitation in the Northwest. (Adapted from Highsmith (*11*).)

Figure 6.3 shows the distribution of rainfall at Pendleton, Oreg., and Lind, Wash., with predominantly winter precipitation, and at Tetonia, Idaho, where the precipitation occurs at a rather uniform rate every month of the year. The winter rainfall in the Northwest permits an alternate fallow–small grain farming system to flourish in lower rainfall areas that would not be possible under summer-type rainfall.

Soils

Most of the soils of the Columbia Plateau, Palouse and Nez-Perce Prairies, and Eastern Idaho Plateaus major land resource areas of the Northwest have been classified as belonging to the order Mollisols, suborder Xerolls, and great groups Argixerolls and Haploxerolls (*54*).

Mollisols develop in subhumid and semiarid warm climates (average annual temperature 47° F. or higher), have friable surface horizons high in organic matter and bases; and are dark brown to nearly black.

Xerolls are formed in climates with rainy winters but dry summers, so that during the warm season these soils are dry for long periods. They are, in general, well drained and usually deep enough to store water adequately. Xerolls are used for range, wheat, and irrigated crops.

Argixerolls (formerly Brunizems) have a subsurface horizon of clay accumulation that is relatively thin and brownish. Haploxerolls (formerly Chestnut and Brown soils), in contrast, have a subsurface horizon high in bases but without large accumulations of clay, calcium carbonate, or gypsum. The distribution of these two great groups of soils in the Northwest area where summer fallow is practiced is shown in figure 6.4.

The soils of these two great groups in the Northwest are fine sandy to silty textured in the lower rainfall areas, but are finer textured silt loams and silty clay loams in the areas of higher precipitation. The organic matter content varies with the amount of precipitation—ranging from less than 1 percent in areas of low precipitation to over 4 percent in the areas of high precipitation. Topography varies from gently sloping to moderately and steeply sloping, with some cropland on slopes of 50 percent or greater. When water supply and fertility are properly balanced, the productivity is high.

Crops and Cropping Practices

The Columbia Plateau in eastern Oregon and Washington (fig. 6.1) receives from 9 to 18 inches of precipitation annually, mostly during the winter. A general cropping practice requires the use of fallow alternately with winter or spring wheat or with winter or spring barley in areas receiving less than 13 inches of annual precipitation. Areas receiving from 13 to 16 inches of annual precipitation are transitional to annual cropping, and summer fallow may or may not be used with these same crops.

In the humid parts of the Columbia Plateau (annual precipitation 16 inches or more) and in the Palouse and Nez-Perce Prairies major land resource area (annual precipitation 18 to 23 inches) annual cropping is practiced with wheat, barley, and peas occasionally in rotation with alfalfa or fallow. Nearly one-half of the Columbia Plateau is cropland, with most of it being dry-farmed to fallow and wheat. About two-fifths of the Palouse and Nez-Perce Prairies is cropland, with nearly all dry-farmed to wheat and fallow and about one-half is rangeland.

The acreages of harvested winter wheat, barley, and dry peas in the Northwest are shown in figures 1.5, 1.7, and 6.5, respectively. Time sequences of cropping and tillage operations for each of the three major land resource areas are as follows:

Time	*Field operations or conditions*
	Wheat-Fallow (Columbia Plateau)
Late June	Harvest wheat
Early September	Fall chisel
September to mid-April	Uncultivated wheat stubble
Mid-April	Initial tillage
Mid-April to mid-September	Cultivate fallow
Mid- to late September	Plant wheat
Late September to late June	Growth of wheat
	Wheat-Peas (Palouse and Nez-Perce Prairies)
Late July	Harvest wheat
Late July to mid-September	Uncultivated wheat stubble
Mid-September	Plow
Mid-September to early April	Bare
Early April	Plant peas
Early July	Harvest peas
Early August	Plow
Early August to late September	Bare
Late September	Plant wheat
Late September to late July	Growth of wheat
	Wheat-Fallow (Eastern Idaho Plateaus)
Late July	Harvest wheat
Early October	Fall chisel
Early October to late April	Uncultivated wheat stubble
Late April	Initial tillage
Late April to mid-August	Cultivate fallow
Mid-August	Plant wheat
Mid-August to late July	Growth of wheat

There are approximately 2,351,000 acres of fallow land in Washington; 953,000 acres in Oregon; 895,000 acres in Idaho; and 127,000 acres in the panhandle of Utah. The acreage of fallow land in the Northwest has not varied greatly from year to year since the midtwenties.

Water Conservation

Storage Efficiency

Soil water storage efficiency may be defined as the net precipitation that is stored in the soil over some given period. The data in table 6.1, showing soil-water storage amounts together with efficiencies at the end of three periods, were taken from locations where longtime average annual precipitation ranged from 10 to 15 inches. Both spring and winter wheat crops are included. Fifty to seventy five percent of the precipitation received over the first winter is stored in the soil. For a dryland fallow system, this is comparatively high, but might be expected as (a) the soil is initially dry, (b) the evaporative demand is low, and (c) the precipitation occurred in effective amounts.

Soil water losses might conceivably result from any one of a combination of several factors, including soil-water and snowpack evaporation, surface runoff, and percolation. It may be concluded, however, that the losses are primarily due to evaporation. Loss of water by percolation contributes to the losses. Percolation losses below the root zone are negligible in most years.

In most areas of the Northwest runoff is not a major factor in soil water losses. However, in areas where runoff is significant, such as in eastern Idaho, fall chiseling has proved beneficial in reducing runoff.

The dryland area of eastern Idaho does not have the pronounced winter rainfall pattern of Washington, Oregon, or northern Idaho. However, the winter period is somewhat extended in eastern Idaho as compared with the other areas; consequently, water storage patterns in these dryland areas tend to resemble each other more than might be expected.

During the summer of the fallow period, when usually only small amounts of precipitation occur, there is a net loss of stored soil water (table 6.1). Water losses during this time could be expected from soil water evaporation, weed transpiration, and surface runoff—usually in that order of relative importance. Summer rains are not normally intense enough to cause runoff. In fact, it was shown that only 8 percent of the summer precipitation in eastern Idaho occurs in sufficient quantities per storm to reestablish liquid film continuity through the dry soil mulch to the stored profile water (*33*). Therefore, most summer rains merely temporarily retard evaporation from stored profile water rather than adding to it. Weeds, if allowed to grow for an extended time, will remove measurable quantities of water from the soil seeding zone with the result that this zone will remain dry throughout the rest of the summer fallow season, although it still allows water to pass through it in the vapor phase (*33*). If fall seeding is done under this condition, germina-

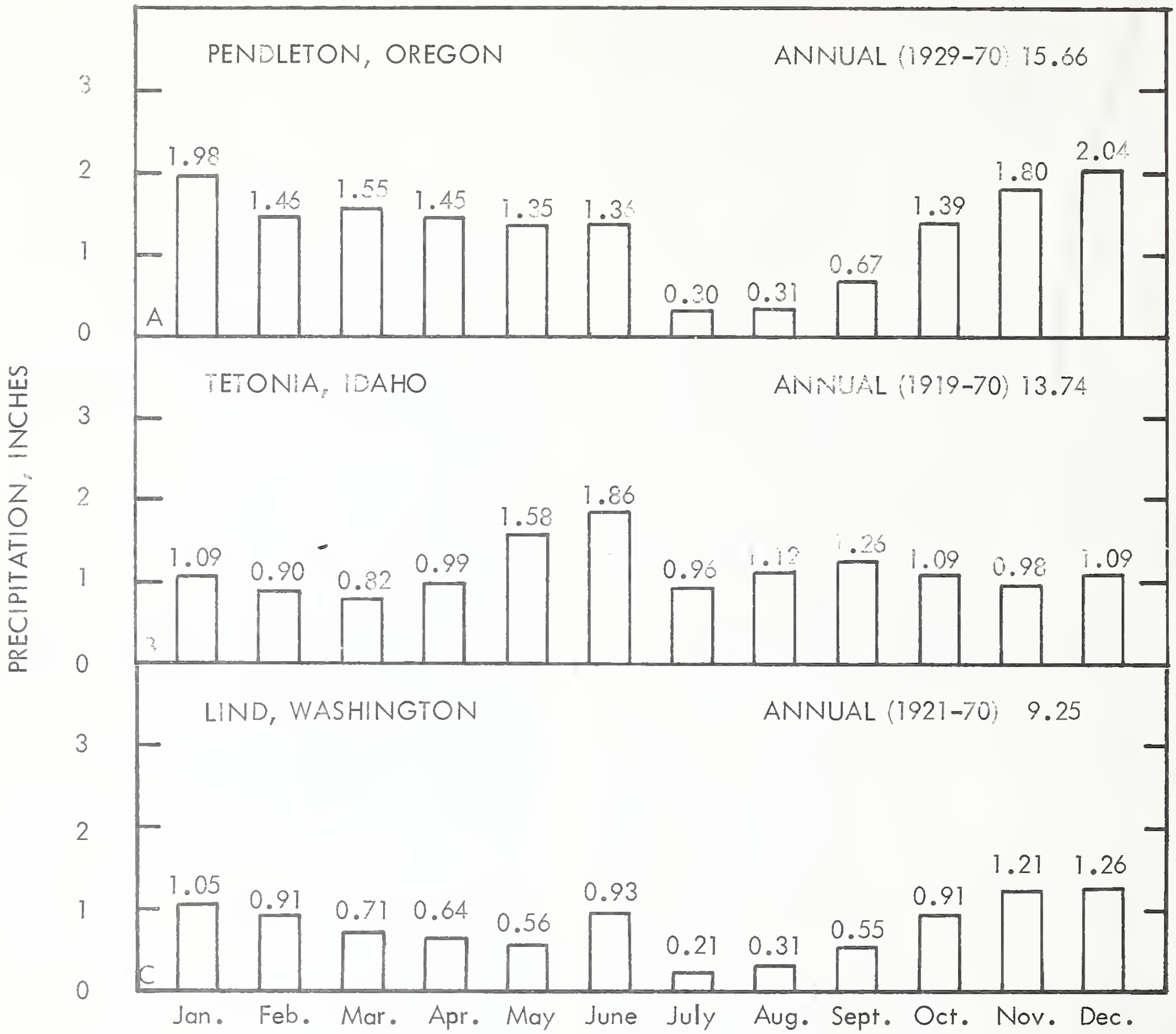


Figure 6.3.—Mean monthly precipitation at Pendleton, Oreg.; Tetonia, Idaho; and Lind, Wash.

tion may be reduced or at least delayed until late fall rains rewet this layer.

There was less soil-water storage during the second winter after harvest at all locations except Harrington (table 6.1). One reason is that infiltration rate continually decreases while the soil profile is being filled. From high initial values on a dry soil, the rate of water entry decreases as the wetted front proceeds downward in the profile (*41*). Runoff, therefore, is relatively higher during the second winter after harvest because infiltration rates are reduced. Another reason is that during the second winter infiltration may be restricted by ice formation or frozen soil conditions. These layers may develop from water that was stored previously, and may not be easily melted, even by runoff water once they have formed because runoff water from snowmelt contains little energy for melting ice. These frozen conditions are prevalent in the eastern Idaho dryland area and at higher elevations of the Oregon and Washington dryland area. The surface layer does not have so good an aggregation during the second winter as it had the first, because the tillage performed normally breaks down soil structure.

When these various soil-water-climate relations

TABLE 6.1.—*Average available water stored per 6-foot soil depth at indicated period, and water-storage efficiency of inclusive storage period*[1]

State and location	Spring of fallow year		End of summer fallow	Spring of crop year		Reference
	Soil water stored	Water-storage efficiency	Soil water stored	Soil water stored	Water-storage efficiency	
	Inches	*Percent*	*Inches*	*Inches*	*Percent*	
Washington:						
Lacrosse	7.1	61	-------------	7.7	29	(*22*)
Ritzville	4.2	52	3.1	6.2	32	(*26*)
Harrington	4.2	54	3.5	8.5	35	(*26*)
Dusty	5.9	69	5.5	8.5	41	(*26*)
Idaho:						
Tetonia	6.6	73	5.0	6.4	30	(*34*)

[1] Inches shown refer to amounts of available water accumulated from harvest to the time indicated. Water-storage efficiency is computed as: Soil water accumulated at the time shown/precipitation from harvest to this same time.

are considered, the amount of water stored (or lost) between the spring of the summer-fallow year and the spring of the crop year (Y) is somewhat dependent on the soil water present in the spring and fallow year (X). This relation is shown in figure 6.6 and depicts that:

$$\hat{Y}=5.4-0.64X$$

$$r=-0.67^{**}$$

In the above equation, $\hat{Y}$ is the estimate of Y at a given value of X; r is the correlation coefficient, and in this case is significant at the 1-percent confidence level. It may be calculated from this equation that the net storage from the spring of the fallow year to the following spring (crop year) will be expected to be relatively high if the preceding storage was low, and if adequate precipitation occurs. Conversely, if the soil water is initially 8.4 inches or more, a subsequent soil water loss is expected. This relation could be easily applied to a spring cereal cropping situation. Provided that acreage allotments were not a factor, a practical management decision could be made in the spring (after harvest) whether to initiate a fallow season or to plant wheat with existing stored soil water. Winter wheat does not lend itself to this analysis in the 10- to 15-inch precipitation areas where these data were taken because it is planted before the initial winter soil water storage period.

The effective capacity of some of the soils in the Northwest to hold soil water is limited by impervious bedrock at varying depths. For example, shallow soils over bedrock are extensive in the Columbia Basin in Oregon, in parts of Washington, and on the Rexburg Bench in eastern Idaho. On these shallow soils, the storage capacity may be completely filled during the winter after harvest; thus, fallowing promotes runoff and erosion during the second winter.

Methods of Tillage

Fallow tillage controls weed growth during the water-storage period and provides a desirable seedbed. The type of implements used may be categorized by the amount of stubble that is left on or near the soil surface. Initial spring tillage with an implement such as a tool-bar cultivator having one large blade or several small sweeps provides a stubble mulch, but moldboard plowing usually leaves very little surface mulch. Disking, depending on the setting of the implement, buries an intermediate amount of stubble.

The effects of using a mulch-type implement versus semimulch- or nonmulch-type on water conservation have been small, slightly favoring the mulch-type (*34*). Therefore, erosion control is the most important consideration in choosing the type of tillage implement, and the mulch-type is definitely favored.

The first spring tillage should be done at an early date, that is, as soon as the soil has dried enough so that the machinery can be used in the

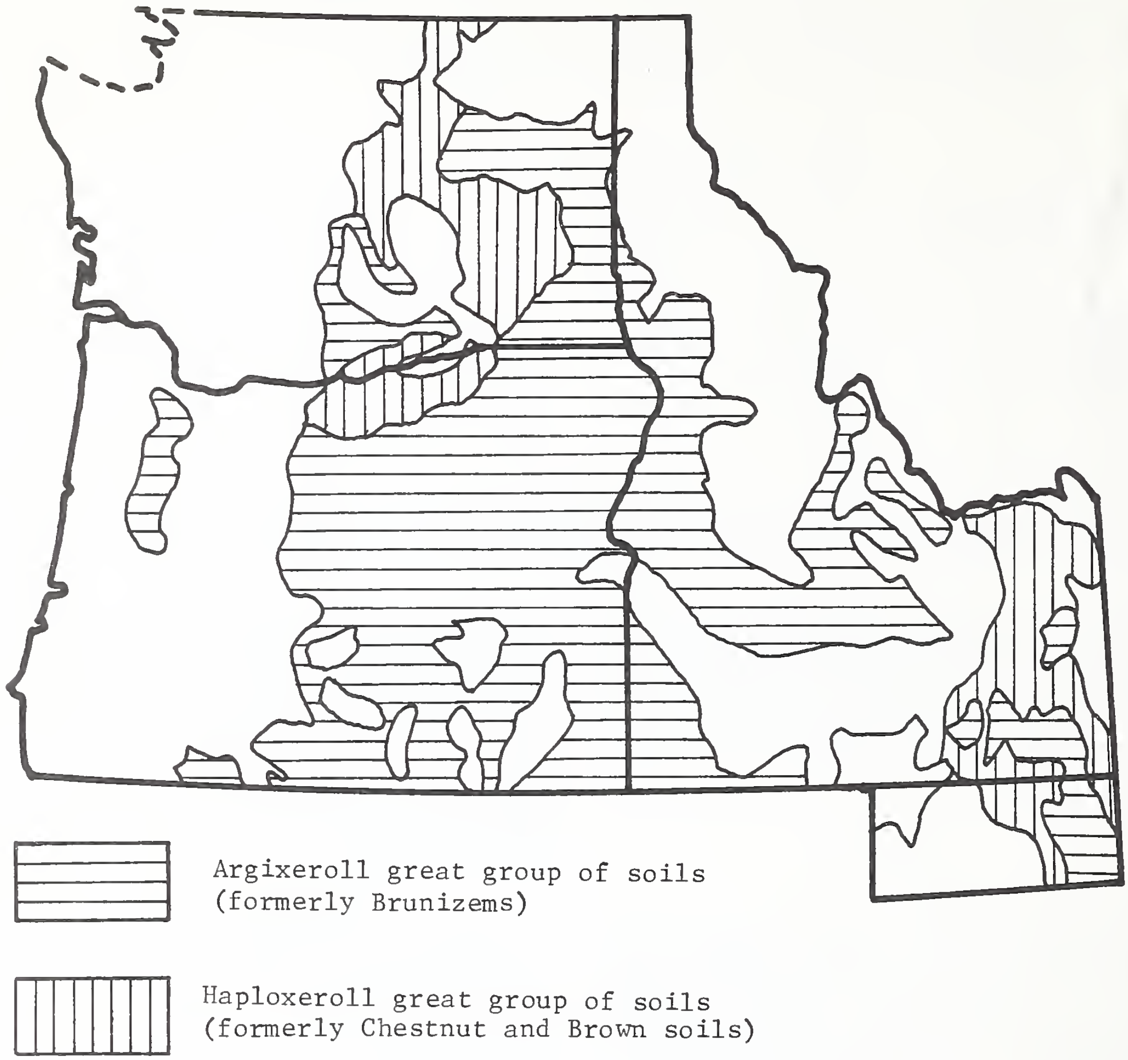


FIGURE 6.4.—Distribution of the two major great groups of soils in the semiarid to subhumid Northwest (*54*).

fields without doing physical damage to the soil structure. At the Pendleton and Moro, Oreg., (*40*), Lind, Wash., (*29, 30*), Nephi, Utah (*3*), and Tetonia, Idaho (*33*) locations, the early tilled fallow was always superior for water storage and subsequent wheat yields as compared with delayed tillage. The early tillage was effective in reducing soil water losses during the summer of the fallow season of this region. Early-season weed transpiration is controlled and soil evaporation is reduced—the latter probably by reducing capillary conductivity to the soil evaporating surface (*39*).

Subsequent tillage for weed control is done with a rod weeder or a duckfoot cultivator. However, during these later operations other major objectives may determine cultivator type, depth or timing. Examples of these objectives are: (a) Reduction of straw length for ease of seeding, (b) creation of a cloddy surface for wind erosion control, (c) renewal of a surface mulch after heavy rainstorms, or (d) firming the seedbed. The rod weeder usually accomplishes objective (d) very well.

Chiseling in the fall after harvest is used extensively in eastern Idaho and in localized areas of Washington, where the soil normally freezes to a shallow depth, to allow water from snowmelt to enter the soil through the chisel mark. An additional 1.5 inches of soil water (30.5 percent more than nonchiseled plots) was stored in Idaho by this method (*34*). Also there was an increase in soil water storage (1.4 inches) during the second winter from rotary subsoiling in the fall after summer fallow, provided this tillage was the last operation. Planting winter wheat after this operation negated the subsoiling effect, whereas if the wheat were planted first the resulting stand was reduced by subsoiling and subsequent yields were also reduced about 1 bushel per acre.

Erosion

Soil erosion by wind and water has long been recognized as a serious problem on the dryland crop areas of the Northwest.

Wind

Erosion by wind is of special concern where annual precipitation is less than 13 inches. Losses of soil by wind erosion were so severe in certain parts of eastern Washington during the 1920's that farmers were faced with the prospect of abandoning their farms. Many averted this fate by shifting to a stubble mulch system of tillage. The principles and advantages of stubble mulch tillage for wind erosion control, and suggestions for accomplishing stubble mulching, were described in early technical bulletins written for the farmers of this region (*18*). Severe wind erosion is still common in eastern Washington and Oregon. Occasionally, roadside ditches become filled with wind-blown soil, and roads become impassable because of soil drifts. Soil is removed from portions of some grainfields and deposited on others to such depths that the crop is destroyed on both.

In a few instances, severe erosion stems from the practice of stubble burning and complete disregard of the principles of stubble-mulch tillage, but combinations of circumstances sometimes defeat the best efforts to control wind erosion. A season of unusually poor crop growth, due perhaps to less than average precipitation, results in decreased amounts of crop residues for creating a stubble mulch in the ensuing fallow season. If this condition happens to coincide with a season of strong and persistent winds, wind erosion is severe and crop stands may be completely destroyed on sizable areas.

FIGURE 6.5.—Distribution of harvested dry pea acreage in 1964 (*11*).

Such circumstances have been experienced in recent times, and have resulted in extensive portions of seeded wheatfields being eroded away to the depth of tillage. Any soil area that has been highly pulverized, such as field corners, roads, and boundaries, where extra traffic or extra tillage for weed control has occurred, is especially vulnerable to erosion by wind. Also, in eastern Washington and Oregon, extensive erosion often gets started on small localized exposures of unconsolidated volcanic ash that produce little or no vegetation.

Although the need for stubble-mulch tillage is generally accepted, the degree to which farmers succeed in producing and maintaining an adequate stubble-mulch condition is variable. A pulverized soil surface is likely to blow even though appreciable amounts of crop residue may be present on the surface and protruding from it. A cloddy surface under the same conditions is erosion resistant. The management systems of successful wheat growers in areas where low rainfall makes fallowing necessary for water conservation are strongly oriented toward overcoming the challenge of wind erosion. Thus, a principal goal is to produce and maintain a cloddy surface and also to preserve as much as possible of the crop residues on the surface throughout the fallow period. However, other goals of the tillage program tend to work against the preservation of clods and crop residues on the surface. Numerous tillage operations are performed during the spring and summer of the fallow year, creating a 4- to 6-inch dry soil mulch. This mulch helps maintain

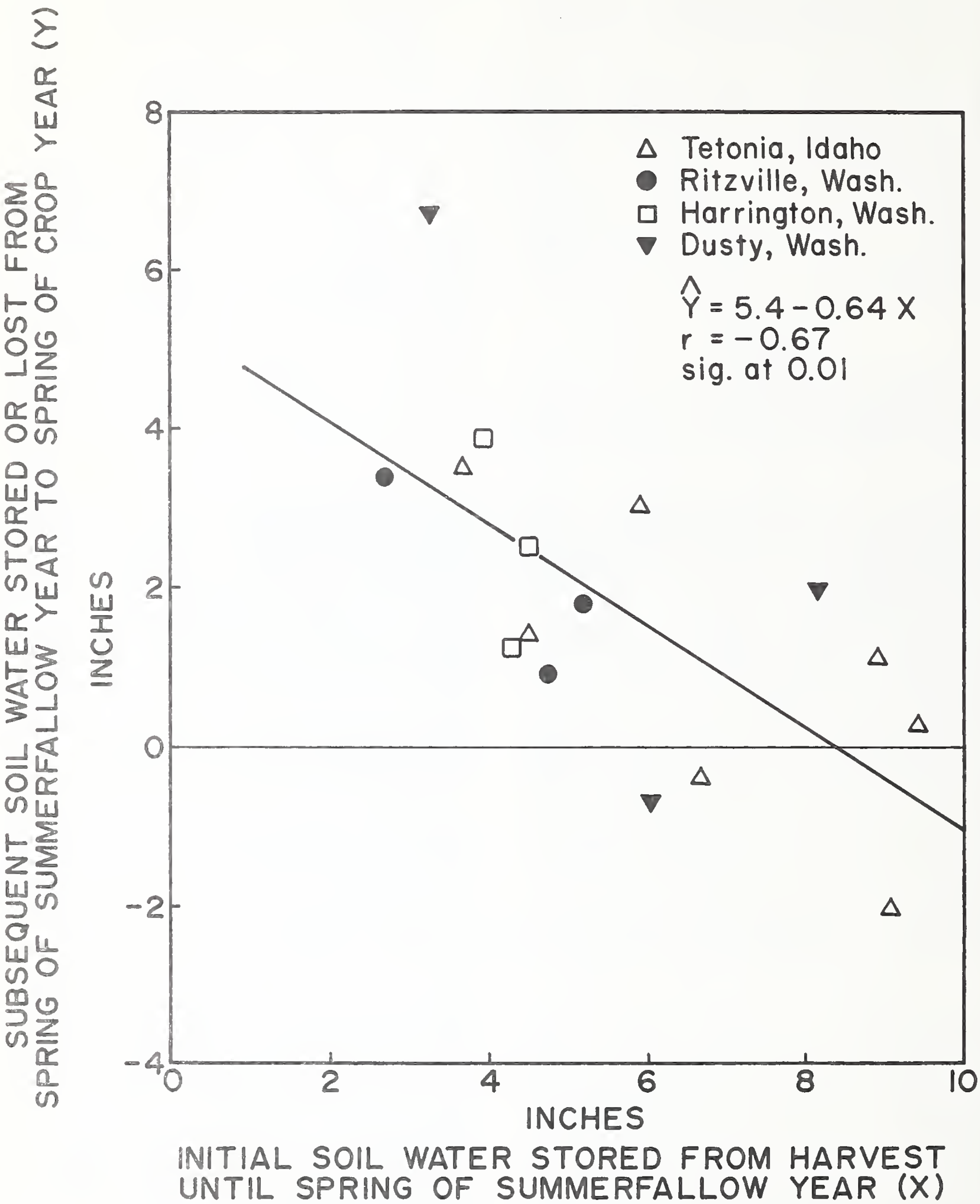


FIGURE 6.6.—Effect of initial water stored in the soil profile from harvest to spring of fallow year (X) on the subsequent water stored or lost from spring of fallow year to spring of crop year (Y) at four locations.

a favorable water content in the seeding zone for germination of the winter wheat crop by restricting evaporative loss of soil water (*18*, *28*, *48*). The soils of low-rainfall regions range from fine sand to silt loam, and are typically weakly aggregated. Such a tillage regime tends to produce a pulverized soil surface highly susceptible to erosion.

Low-speed operation of grain drills can help to avoid further burial of meager surface residues by the seeding operation. Open (spoked) press wheels seem to throw more soil up onto the straw than do closed-face press wheels, which do not pick up soil but merely push it aside.

On coarser textured soils in north-central Oregon, if wheat is seeded after the soil surface has been moistened about an inch deep by late-summer rainfall, the surface crust will break up into small clods that aid greatly in wind erosion control.

Reseeding with a deep-furrow drill at right angles to the prevailing wind direction, is an effective countermeasure on severely eroded areas. The immediate benefit of this practice derives from the ridged surface configuration thus created, and the possibility that clods or crop residues may be brought to the surface and help to stabilize the ridge crests. Spreading a straw mulch on critical areas and lightly disking it in is another effective emergency measure used, but it is costly and laborious. Emergency tillage, as a temporary measure to provide a rough, cloddy, erosion-resistant surface, is described by Hunter (*18*) and by Woodruff and others (*55*). It consists essentially of the use of cultivators or chisels at right angles to the wind direction, deep enough to bring up clods, and slowly enough to avoid pulverizing the clods.

Water

Soil erosion by water is also an important problem in the grain-fallow farming areas of the Northwest. It is largely a consequence of the pulverizing effect of numerous tillage operations on the fine-textured, weakly aggregated soils.

Several field plot research studies have been conducted at Pullman, Wash., to evaluate the effects of various crop rotations, tillage, and residue-handling treatments on runoff and soil erosion. Examples of results of these studies (*12*, *13*, *36*) are given in tables 6.2 and 6.3.

These data were obtained from field plots only 54 or 90 feet long; they are therefore useful mainly for comparing the relative effects of different cropping systems or tillage treatments. On farm fields, where slopes are typically several hundred feet long, soil losses due to rill erosion have been estimated by Soil Conservation Service technicians at well over 100 tons per acre in a single season.

TABLE 6.2.—*Effect of preceding crop on annual soil losses due to erosion on plots seeded to winter wheat, 1938–56*

Crop preceding winter wheat	Soil loss
	Tons/A
Winter wheat after:	
Alfalfa-grass	1.3
Wheat [1]	1.4
Sweetclover-grass	2.9
Peas	4.3
Summer fallow	9.3

[1] Soil loss measured during second wheat crop year after 4 years of alfalfa-grass.

Two principal conclusions were drawn from the field research cited above:

1. The most important factors in erosion control on croplands during a particular season are the degree of surface protection provided by vegetative material, either living or dead, and surface roughness. Thus, the most severe erosion occurred on plots seeded to wheat after summer fallow, where plant residues had been buried or destroyed and soil cloddiness eliminated by numerous tillage operations.
2. A crop rotation exerts a direct effect in controlling soil erosion, determined by the proportion of time that the land surface is protected by effective vegetative cover. Wheat after fallow is the most hazardous condition, because during half of the winter erosion seasons the soil surface is highly pulverized and devoid of crop residues if the alternating wheat-fallow sequence is strictly followed.

The practice of summer fallowing has long been recognized as the underlying cause of severe water erosion, whether it be associated with the prolonged rains and frozen soil of winter or the infrequent, brief, but devastating summer thunderstorms (*45*, *46*). Therefore, shifting to annual cropping could provide considerable relief. Annual cropping is practiced successfully where average annual precipitation is 16 inches or more (*14*), and can be

TABLE 6.3.—*Average annual soil erosion losses measured under different crop rotations, 1938–56*

Crop rotation	Soil loss [1]	Time in winter wheat
	Tons/A	*Percent*
Alfalfa-grass (4 yr.)-wheat-wheat-peas-wheat	0.7	38
Sweetclover-grass (2 yr.)-wheat-peas-wheat	1.4	40
Wheat-peas	2.3	50
Wheat-fallow	4.7	50

[1] Averaged over all years of the rotation.

practiced with varying success in the 15- to 16-inch rainfall areas although an occasional fallow may be beneficial for weed control or if winter precipitation is exceptionally low. Spring-seeded crops usually do not deplete the available soil water to such great depths as does winter wheat, probably because their growing season is short and their root systems do not develop so extensively. Such crops leave some available water in the profile, which a following wheat crop can utilize effectively. Winter wheat, with its much greater yield potential, can thus be grown in rotations with spring grains where the average precipitation is marginal for its successful culture. Moreover, spring grain crops in the rotation provide opportunities for weed-control tillage at critical times.

However, summer fallowing became prevalent in these regions of higher rainfall because it was early realized that a deficiency of available nitrogen was the main factor limiting wheat production and because it was known that the extra tillage of the fallow season would enhance the release of nitrogen from the soil organic reserves (*29*, *30*, *48*, *49*). Although the advent of low cost nitrogen fertilizers and efficient methods for their application have reduced the acreage of summer fallow in the high-rainfall areas, for various reasons summer fallowing is still widely practiced. Approximately 20 percent of the cropland in eastern Whitman County, Wash., where precipitation is sufficient to support annual cropping, is now fallowed. This higher rainfall area of the Palouse region experiences some of the most severe and spectacular soil erosion that occurs on agricultural lands. The first tillage operation of the fallow year is, in almost all instances, fall or spring moldboard plowing, which effectively buries most of the crop residues. This is followed by numerous (typically 6 to 10) tillage operations throughout the spring and summer seasons, for weed control and for establishing a soil mulch to aid in preserving water in the upper soil profile. Much of the potential value of the water stored just beneath the dry soil mulch is lost because of shallow seeding with double-disk drills, which usually do not place the seed deep enough to reach the stored water.

The most erodible soil physical condition possible—highly pulverized and virtually devoid of exposed crop residues, completely vulnerable to the slaking and crust-forming effects of alternate wetting and drying, freezing and thawing, which occur during the autumn and winter—is created by the tillage program described above. Moreover, the capacity of the soil profile to store water during the winter of the crop year, which is the season of high erosion hazard, is diminished by the amount of water still stored from the precipitation of the fallow year. These soil physical factors, coupled with the steep and irregular topography of the eastern Washington Palouse region, and especially of central and eastern Whitman County, result in serious erosion and sedimentation problems. Erosion by water is typically a winter phenomenon in this region, where the eroding agent is surface runoff derived from low intensity rainfall sometimes combined with snowmelt water. The infiltration capacity of the crusted surface is sometimes further reduced by soil freezing, the occurrence and intensity of which varies over the region depending on elevation, latitude, and slope. The most severe soil erosion is usually associated with rising temperatures accompanied by rain following a period of cold weather during which the soil was frozen to depths of an inch or more. The incoherent slurry of pulverized soil that results from this wetting and thawing is easily carried off by even relatively small volumes of water, which runs off in easily formed rills because it cannot infiltrate the fine-grained frozen soil. Also, severe rill erosion often results from intermittent to nearly continuous rainfall for several days on unfrozen soil, although the intensity seldom exceeds 0.1 inch per hour even for short periods.

The same measures that reduce or control erosion by wind are effective against erosion by water. Soil clods and crop residues on the soil surface and mixed with the soil near the surface are effective in reducing surface sealing and retarding the flow of runoff water.

Horning and Oveson (*15*), studying annual cropping systems, concluded that finely tilled seedbeds are not essential for growing wheat. However, cloddy seedbeds such as were used by these workers cannot be created or maintained in fallow systems as now commonly practiced.

Also highly beneficial, in addition to surface cloddiness, is the extra growth of foliage that results from early seeding and early emergence of the winter wheat crop. Sievers and Holtz (*48*) noted the tendency of winter wheat to tiller profusely when seeded early on soil having a good supply of moisture near the surface. They related this early growth and tillering to greater yields of grain. Later, the erosion control value of the extra growth due to early seeding came to be widely recognized and was the subject of a report by Cochran and others (*6*). However, early seeding favors root rot disease and yield reductions due to this disease have severely restricted the use of early seeding for erosion control.

Early emergence and vigorous fall growth are likely to result only if the wheat seed is placed deep enough to contact moist soil beneath the loose, dry soil mulch. Deep furrow grain drills with 14- or 16-inch row spacing are used almost exclusively in the true grain-fallow regions of the Northwest, but this technique has not yet been widely accepted on the steep and rolling terrain of the eastern Palouse region. The ridged and furrowed surface produced by these implements is also an effective erosion control measure, especially if seeding is done across the field slope or as nearly on the contour as practicable. Unfortunately, the general practice with most tillage and seeding operations is to start at an edge of the field and work around it, progressing toward the center. Explicit attempts to orient cultural operations with respect to either the prevailing direction of erosive winds or slope direction are the exception rather than the rule.

A very effective means of erosion control at every farmer's command, whether the eroding agent be wind or water, is vigorous crop growth, which can usually be produced by careful management and full use of the limited water supply (in the obligatory summer-fallow areas), plus judicious use of nitrogen fertilizers, and early seeding of winter wheat with deep furrow drills (*6*). This provides foliar protection of the surface against raindrop impact, which may be important to these weakly aggregated soils even though the rainfall of the region has very low intensities and is comprised of very small drops. Another major benefit of vigorous crop growth derives from use of the greater amounts of crop residues in a stubble-mulch tillage program, which provides protection during the fallow season as well as the early part of the crop year. The aerodynamic and hydrodynamic roughness properties of vigorous, well-stooled young wheat plants, of crop residues on the soil surface, and of the ridges created by the deep-furrow drill all contribute to amelioration of the soil-erosion hazards of wind and water.

The great importance of vegetative cover or even small amounts of crop residues on the soil surface for erosion control has long been recognized, and their use for this purpose recommended (*6*, *12*, *28*, *29*). However, the most effective step that could be taken for reducing the extremely heavy losses of soil due to water erosion, in the annual cropping region, would be to abandon the summer fallow practice. As long as soils on the steep slopes in the Palouse region are stripped of protective residue cover by moldboard plowing, and then thoroughly pulverized by fallow season tillage, there seems to be no effective means of erosion control. Annual cropping depletes the soil profile reservoir every summer, affording safe and beneficial storage for precipitation during the winter, and provides crop residues for surface protection during every erosion season, if properly managed. Of supreme importance, however, is the cessation of the intensive tillage being used in summer fallow. This will require the development and adoption of methods of weed control requiring less tillage, or combinations of mechanical and chemical measures that will provide adequate control of weeds while keeping soil clods and much of the crop residues on the land surface.

Soil Fertility

When dryfarming was initiated in the Northwest, all essential nutrients were present in adequate amounts to meet the plant needs within the level of production dictated by the available water supply and management practices. With continued cropping, N became deficient; consequently, the fallow-wheat farming system became dominant in areas receiving less than 18 inches average annual precipitation. This system not only assured a greater supply of available water throughout most of the area, but also resulted in release of essential nutrients, mainly N, through mineralization of soil organic matter. The use of fallow to augment the supply of available nutrients is a destructive practice that inevitably depletes the soil's supply of organic-derived nutrients. The practice also enhances nutrient loss by erosion and leaching, and thereby accelerates the destructive aspects of the system. At the present time (1972), N, S, and P are the only nutrients known to be deficient under dryland conditions over sizable areas of the Northwest.

Nitrogen and Carbon

Organic C and N contents of Northwest soils have decreased with time under the summer-fallow system of farming (*4*, *5*, *23*, *48*, *52*). The N losses reported ranged from 0 to about 33 percent of the initial N content of the soils over periods of time ranging up to 63 years; the corresponding decreases in C were higher over the same periods. Caution should be exercised in interpreting these results because the decreases were based on the N and C contents of paired samples taken from cropped and adjacent uncropped soils. Differences obtained in this manner result from all aspects of farming, as well as inherent differences in the soils before farming began.

Stephens (*51*) presented the first data from a controlled experiment wherein the deleterious effects of the wheat-fallow system of farming on the N status of soil in the Northwest were measured. The N content of the surface foot of soil decreased from 0.088 percent in 1922 to 0.077 percent in 1932—a decline of about 12 percent in 10 years. No comparative data were given for other farming systems included in the experiment.

A comprehensive study of soil N and C was made at Pullman, Wash., (*50*) from 1921 through 1944. The study was unique within the area because N fertilizer was included among the treatments and direct comparisons were possible between the wheat-fallow and annual cropping systems of farming. The data clearly show a depletion of soil N for all treatments used in the wheat-fallow system (table 6.4). The straw plus ammonium sulfate treatment most nearly meets the agricultural needs of present-day farming in the area. Yet it fails to overcome the deleterious effects of the system on N and C losses. This same treatment, when applied each year under annual cropping, resulted in a definite increase in soil C and N. This treatment approaches the practice used successfully under annual cropping in the Palouse region today, although higher rates of straw and N are used now. The most effective treatment included in the study was the application of 6 tons of barnyard manure per acre. The manure contained only 50 pounds of N per acre, yet there resulted from it only a small loss (4.4 percent) of soil N under fallow and a large increase (16 percent) in soil N under annual cropping.

Table 6.4.—*Carbon and nitrogen changes in the surface foot of Palouse silt loam as influenced by straw N fertilization, and cropping sequence over the period 1921–44* (*50*)

Cropping system and treatment	C	N
	Percent	*Percent*
Annual cropping:		
None	+1.4	−1.3
Straw	+3.2	−1.4
Straw+AS	+20.4	+10.4
Manure	+21.3	+16.0
Wheat-fallow:		
None	−8.0	−12.1
Straw	−6.6	−9.8
Straw+AS	−3.6	−7.5
Manure	+2.6	−4.4

[1] None, stubble utilized; straw, 2,700 lb. per acre added; AS, ammonium sulfate (59 pounds of N per acre); manure, 6 tons per acre supplying 50 pounds of N per acre.

Results from a 34-year study conducted on Walla Walla silt loam at Pendleton, Oreg., (*38*) are reported in table 6.5. These results, as well as those obtained at St. Anthony, Idaho, (*34*) (table 6.6), parallel those obtained in the Pullmanst udy. Under the wheat-fallow system of farming, a general loss of N (and presumably C) occurred with time except where extremely high rates of residue were returned to the soil. It is noteworthy that biennial applications of 10 tons of manure per acre at Pendleton increased the soil N by 7.5 percent over the 34-year period.

The results of the Pullman, Pendleton, and St. Anthony studies indicate that two important factors determining the direction and the degree of change in soil N level with time are: (a) The amount of residue returned to the soil, and (b) the amount of N contained in the residues or supplied as N fertilizer. These factors are not the only ones to be considered, for they must be placed in perspective with respect to climate, moisture, available nutrients, and the level of soil N already present in the soil. Under the conditions generally present over the wheat-fallow areas of the Northwest, it is most likely that soil N levels will equilibrate to new levels that are consistent with the environment, the system of farming, and the amounts of residue returned to the soil.

Presumably, over the many years before the use of N fertilizers, the amount of N mineralized during a fallow or growing season decreased with time in a parallel fashion to the decreases already reported for total N. With the use of N fertilizer, however, this trend may have been slowed or even reversed, but no direct long term measurements have been reported showing the trend of mineralizable N over the years. On a short term basis, residual effects of applied N have been measured in terms of NO_3-N produced during a fallow (*26*) and in terms of wheat yields (*16*, *22*, *26*).

In addition, the yield data presented by Oveson (*38*) for the Pendleton study clearly indicate an increasing effect of N fertilizer on wheat yields throughout the 34-year period. A comparison of yields for the straw and straw+30 N treatments show divergent trends; both decrease, but yield for the straw treatment decreases faster. During the first 7-year period, the difference in yield was about 3 bushels per acre in favor of the straw+30 N, but in the fifth period the difference had increased to about 10 bushels per acre in favor of straw+30 N. Thus, yield trends resulting from these treatments parallel the corresponding trends in total N. It is reasonable, therefore, to assume that mineralizable N decreased over the years in the straw-treated soil. Similar trends were not noted for the Pullman (*50*) data, but this may be due to the higher level of soil organic matter at the latter location and the choice of N rates.

TABLE 6.5.—*Wheat yields and changes in the N status of the surface foot of Walla Walla silt loam at Pendleton, Oreg. after 34 years in the wheat-fallow system of farming as affected by residue management* (*38*)

Treatment [1]	Average wheat yield (1931–64)	N lost, percent of 1931 value
	Bu./A.	
Straw	36.7	−13.1
Straw+30 N	43.2	−8.3
Straw+10 tons Manure	49.5	+7.5

[1] Straw, stubble (approximately 4,200 lb./A); straw+30 N, approximately 5,400 pounds of straw per acre and 30 pounds N per acre as ammonium sulfate; straw+10 T manure, approximately 5,400 pounds of straw and 10 tons of strawy manure per acre.

TABLE 6.6.—*Changes in the organic matter content of soil as affected by straw additions under the wheat-fallow system of farming near St. Anthony, Idaho, 1940–58* (*34*)

Treatment	Organic matter change, percent of 1940 value
Stubble burned	−8.9
Straw 2,000 lb./A	−3.6
Straw 4,000 lb./A	0

Nitrogen fertilization has proved more beneficial for Gaines and Nugaines wheat varieties (released in 1962 and 1966, respectively) than for most other previously used varieties. Published information is very limited, but a yield increase of from 19 to 24 percent has been reported for Gaines over other varieties in a 15-inch rainfall area. The preferred rate of N fertilizer was about 80 pounds per acre.[3]

Sulfur

In many dryland soils of the Northwest, the soil organic matter contains most of the total S in the profile. Complete data are lacking, but Harward and others (*10*) give values of 90 and 137 p.p.m. organic S for the 0- to 6-inch layers of Walla Walla and Athena soils, respectively. The organic fraction of these important dryland soils contain N and S in the ratio of about 10 to 1. Consequently, the end products of mineralization for these nutrients, NO_3-N and SO_4-S, are produced in about the same ratio. Plants require most of their S as SO_4-S.

Roberts and Koehler (*44*) determined the distribution of SO_4-S in profiles of several important dryland soils of the Northwest. In general, they

[3] RAMIG, R. E. ANNUAL RESEARCH REPORTS. Columbia Plateau Conservation Research Center. Agr. Res. Serv., U.S. Dept. Agr., Pendleton, Oreg. 1962–65.

found only small amounts of SO_4-S in the surface layers but greater amounts in the subsoil below the 3-foot depth. The depth at which SO_4-S increased was related to rainfall and soil texture. Presumably enrichment in the subsoil resulted from deposition of mineralized SO_4-S leached from the surface soil by winter precipitation.

Because of the intimate relation between N and S in the organic matter, S is subject to depletion from the soil by some of the same processes as is N; leaching and erosion are important ones. Besides being present as a constituent in organic matter, S is conserved in acid soils as SO_4-S by adsorption to the mineral matter, and it may be precipitated by Ca as gypsum in soils or soil horizons rich in bases.

Phosphorus

In contrast to the emphasis placed on N, and to a lesser extent on S, in dryland soils of the Northwest, P has received relatively little attention. In general, the surface soils of the area are well supplied with available P, and, since wheat is not considered a high-P-requiring crop, yield responses to P fertilization are relatively few. Consequently, the immediate need for information on P has not been urgent. Throughout much of the area, levels of available P in the soil decrease to extremely low values below about the 1-foot depth. The supply of available P below about 1 foot is entirely inadequate to sustain economic plant growth. Most of the dryfarmed area of the Northwest has rolling to hilly topography and subsoils have become exposed on hilltops and ridges as a result of erosion by wind, water, and tillage. Thus, significant acreages low in available P are now being farmed. The acreages thus affected, however, represent only a small percentage of the tillable land.

Crop Yields

As early as 1918, Hunter (*18*) stated fallow was necessary for crop production where the rainfall was less than 18 inches per year in Washington. Later Mathews (35) reported fallow was necessary for satisfactory crop production when the rainfall was less than 15 inches in Washington and less than 14 inches in Oregon; 40 percent of the dry-farmed land in Washington and 47 percent in Oregon was in fallow. He also reported fallow was needed for crop production on the high plateau of southeastern Idaho, where about 30 percent of the dry-farmed land was fallow each year. More recently, Jacquot (*22*); and Leggett and Nelson (26) have shown successful annual cropping is possible in Washington for most years in areas receiving only 13 inches or more precipitation per year when balanced with proper fertilization. This decrease in annual precipitation required for successful annual cropping results in part from mechanization, which permits early and timely tillage operations for moisture conservation, and from the use of commercial fertilizer.

Yield increases of dryland wheat resulting from N fertilization are common over much of the Northwest. Even in low rainfall areas, overwhelming evidence has been accumulated over several years that indicate the widespread occurrence of N deficiency of wheat grown on fallow. Data already presented (table 6.5) indicate that 30 pounds of N per acre applied for each crop was beneficial over a 34-year period at Pendleton, Oreg. Jacquot (*22*) shows marked yield increases resulting from N fertilization in eastern Washington. Jackson and others (*21*) reported that N fertilization increased wheat yields in 29 of 35 experiments conducted in areas of eastern Washington receiving less than 13 inches average annual rainfall. Summaries of 5 years' data (tables 6.7 and 6.8) for eastern Washington (*27*) and 4 years' data for eastern Oregon (*16*), all from areas receiving less than 15 inches average annual rainfall, overwhelmingly support the use of N fertilizer in these areas. Peterson (*42*) reports yield increases with N fertilization in 10 of 14

TABLE 6.7.—*Number of experiments conducted on fallow in less than 15-inch rainfall areas of eastern Washington where near maximum wheat yields resulted from various levels of N fertilization* (*27*)

Year	Number of experiments	Number of experiments with highest yield associated with N rates (lb./A) of—					
		0	20	30	40	60	80
1953	8	2	5	0	0	1	0
1954	10	1	5	2	1	1	0
1955	11	4	5	1	1	0	0
1956	12	2	3	1	5	0	1
1957	11	2	5	0	2	2	0
Total	52	11	23	4	9	4	1

TABLE 6.8.—*Number of experiments conducted on fallow in less than 15-inch rainfall area of eastern Oregon where near maximum wheat yields resulted from various levels of N fertilization (16)*

Year	Number of experi-ments	Number of experiments with highest yield associated with N rates (lb./A) of— 0	20	40	60	80	100
1954	40	12	7	13	5	3	0
1955	41	19	7	9	4	2	0
1956	39	3	3	16	7	7	3
1957	32	9	13	5	5	0	0
Total	152	43	30	43	21	12	3

experiments conducted in northern Utah during the period 1942–48. Similar results are reported for the dryland area of southeastern Idaho by Schaeffer and Klages (*47*) and McKay (*31*); in 21 of 46 experiments, wheat yields were increased by N fertilization in the area during the period 1955–1965.

Yields of wheat after fallow and after small grains with and without nitrogen fertilizer are presented in table 6.9 for some locations in the Northwest. The yield of winter wheat after fallow was more than 200 percent of the yield of winter wheat after small grains at all locations when nitrogen was not used. Application of nitrogen fertilizer materially reduced the yield advantage of fallow at some locations. Unfortunately, long term information is not available for the comparison of crop production after fallow and under recropping when adequate fertilizer was used.

At Tetonia, Idaho, an area of low annual but uniform monthly precipitation, the advantage of fallow for spring wheat without nitrogen fertilizer was not so great as it was at Moro and Pendleton, Oreg., where 70 percent of the annual precipitation occurs from November 1 to April 30. Application of nitrogen fertilizer did not change this relationship at Tetonia, Idaho; no comparable data are available for Moro and Pendleton. Yields of other crops after fallow and in rotations are listed by Mathews (*35*). Because the national production control and price support program is based on acreage allotments and because greater yields per acre are usually obtained from winter wheat after fallow, fallow is frequently used in the Palouse and Nez-Perce Prairies major land resource area (fig. 6.1). However, it cannot be justified on the basis of need for conserving water, controlling weeds, or stabilizing production.

Because a crop is obtained in alternate years on land that is fallowed, it is commonly thought that yields after fallow should be at least double the yields obtained on recropped land. However, fallow may still be an economical practice if production is only 180 percent of the yield on annual cropping, because crop production costs are incurred only once every 2 years and crop failures are less likely.

Fallow reduces the probability of crop failures compared with continuous cropping, as shown by curves (figs. 6.7 and 6.8) derived from earlier long-time data obtained from Moro and Pendleton, Oreg., and from Pullman, Wash. The curves indicate the probability of obtaining a specified or higher yield from wheat-fallow and from annual cropping. For example, assuming that less than 10 bushels per acre is a failure, then continuous cropping would produce 10 bushels or more 60 percent of the time at Moro, 93 percent at Pendleton, and 87 percent (without amendments) at Pullman. Wheat on fallow produced 10 bushels per acre nearly 100 percent of the time at Moro, over 25 bushels per acre 100 percent of the time at Pendleton, and over 20 bushels per acre 100 percent of the time at Pullman. The addition of straw had little effect on the curve for continuous cropping, but lowered the curve for wheat-fallow at higher percentage values (compare figs. 6.8*A*, *B*, and *C*). The application of straw plus 60 pounds of N per acre as $(NH_4)_2SO_4$ raised the curve for continuous cropping much more than for wheat-fallow (compare figs. 6.8*B* and 6.8*C*); thus indicating, as mentioned above, that the yield advantage of fallow can be materially reduced by the application of nitrogen fertilizer. Unfortunately, similar long term data are not available for comparing wheat yields from wheat-fallow and continuous cropping systems at all locations for various wheat varieties, farming practices, and fertilizer types and rates. However, the curves do provide one means of comparing yield performance as associated with inherent differences between the Northwest and the other regions shown in figure 1.8.

Yield responses to S fertilization have been obtained on wheat and barley grown under dryland conditions in the Northwest (table 6.10). In eastern Washington, yield increases resulting from S fertilization occurred in 13 of 45 experiments. Visible effects on the vegetation were observed in seven of the remaining experiments (*43*). Other work has dealt with rates and particle size of S fertilizer (*24*). In Oregon, yield responses to S fertilization were measured at three locations, and possible responses at 4 others out of 173 experiments conducted (*16*). Other studies in Oregon have dealt with the residual effects of S under different cropping systems. The conditions in northern Idaho are similar to those for eastern Washington. Some of the Idaho work, including a discussion of the effects of S deficiency on wheat quality, has been summarized (*9*). So far as is known, S deficiency of cereals has not been observed in southeastern Idaho or northern Utah.

In eastern Oregon and Washington, and in northern Idaho, S deficiency in cereals usually occurs at high levels of N fertilization. It is more likely to occur on spring-seeded than on fall-seeded cereals and under annual cropping than on fallow. Thus, the combination of conditions most likely to result in S-deficient wheat is where spring wheat is grown under annual cropping, under favorable moisture conditions at high levels of N fertilizer, and with the sole supply of S that mineralized

TABLE 6.9.—*Yields of wheat grown on fallowed land and after small grains with and without nitrogen fertilizer in the Northwest*

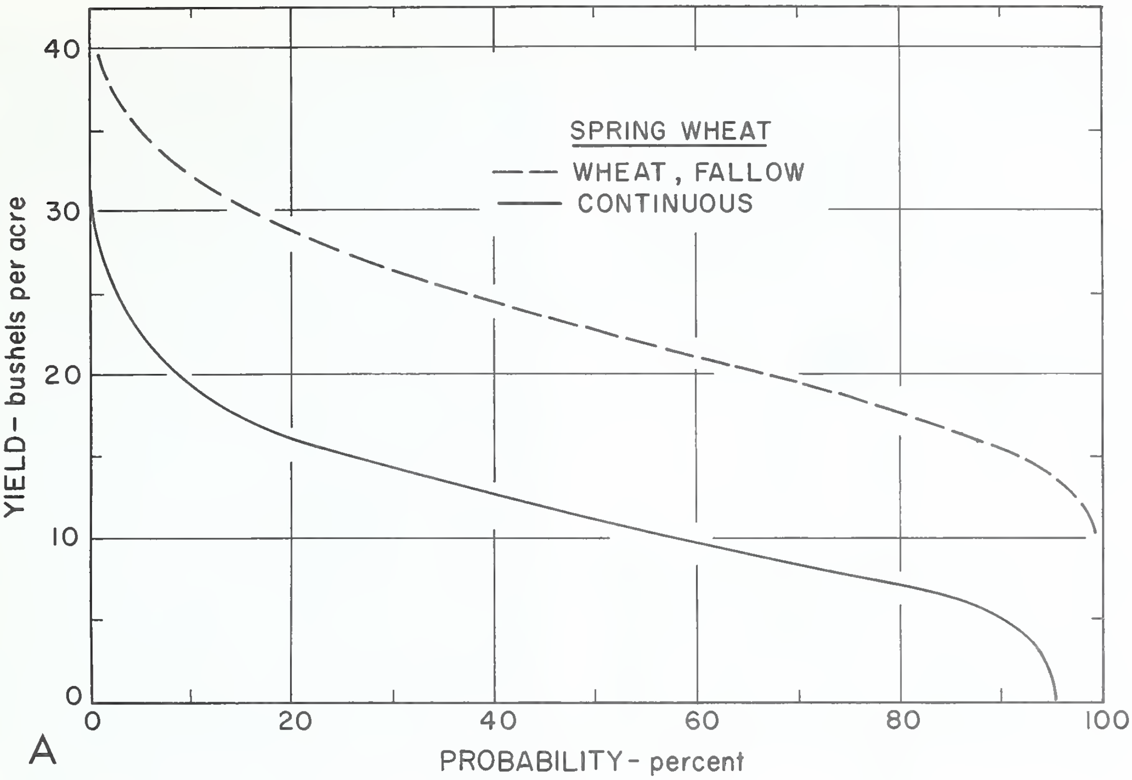
State and location	Years	Average annual precipitation	Nitrogen applied [1]	Yield (bushels/A) on fallow		Yield (bushels/A) after small grains		Yield on fallow as percentage of yield after small grains		Reference
				Winter wheat	Spring wheat	Winter wheat	Spring wheat	Winter wheat	Spring wheat	
		Inches	*Lb./A.*					*Percent*	*Percent*	
Washington:										
Pullman	1922–45	20.29	0	44.1	------	20.0	------	221	-------	(*50*)
Lacrosse	1948–51	15.41	0	34.0	------	16.9	------	201	-------	(*22*)
Dusty	1953–57	12.28	0	38.0	------	------	------	-------	-------	(*26*)
Harrington	1953–57	11.57	0	41.0	------	------	------	-------	-------	(*26*)
Ritzville	1952–57	11.30	0	21.0	------	------	------	-------	-------	(*26*)
Oregon:										
Pendleton	1931–53	16.07	0	44.5	44.1	12.1	16.1	368	274	
Moro	1912–51	11.55	0	------	23.5	------	11.6	-------	203	
Idaho:										
Tetonia	1940–48	14.54	0	27.2	------	[2] 11.2	------	243	-------	(*34*)
Tetonia	1955–61	13.59	0	------	19.8	------	[3] 12.1	-------	164	(*32*)
Tetonia	1955–61	13.59	0	------	19.8	------	[4] 14.5	-------	127	(*32*)
Washington:										
Pullman	1922–45	20.29	60	45.1	------	31.1	------	145	-------	(*50*)
Lacrosse	1948–51	15.41	60	46.9	------	38.8	------	121	-------	(*22*)
Dusty	1953–57	12.28	60	46.0	------	29.0	------	159	-------	(*26*)
Harrington	1953–57	11.57	30	46.0	------	23.0	------	200	-------	(*26*)
Ritzville	1953–57	11.30	20	24.0	------	13.0	------	185	-------	(*26*)
Oregon:										
Pendleton	1944–50	16.57	60	47.8	------	25.4	------	188	-------	
Idaho:										
Tetonia	1955–61	13.59	40	------	20.1	------	[3] 12.7	-------	158	(*32*)
Tetonia	1955–61	13.59	40	------	20.1	------	[4] 16.7	-------	120	(*32*)

[1] When nitrogen was applied, the rate reported gave optimum yields.

[2] Wheat after wheat was severely infested with downy bromegrass (*Bromus tectorum*) at end of the 9 years. Precipitation was slightly above longtime average.

[3] Small grain stubble, not fall chiseled.

[4] Small grain stubble, fall chiseled.



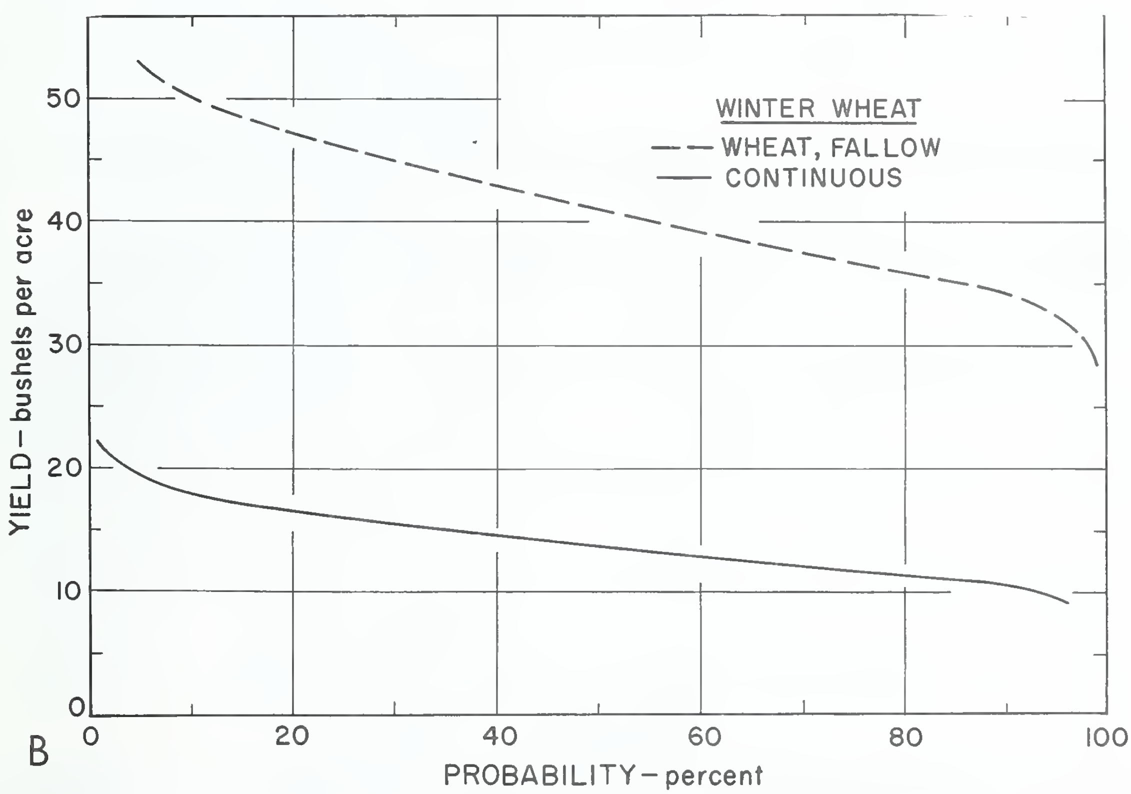


FIGURE 6.7.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at: *A*, Moro, Oreg., 1912–15; *B*, Pendleton, Oreg., 1931–53.

Table 6.10.—*Effect of S fertilization on the yield of dryland wheat and barley grown in eastern Washington 1953–57 (43)*

Cropping system and crop	Number of sites showing		
	No effect	Color response	Yield increase
Wheat-fallow:			
Winter wheat	12	3	0
Spring wheat	3	3	1
Annual cropping:			
Winter wheat	3	0	1
Spring wheat	6	1	7
Spring barley	1	0	4

from the soil organic matter during the growing season. Under these conditions, the ratio of available N to available S, that is, (fertilizer N+mineralized N)/(mineralized S) is greater than the N/S ratio of the plants, thus, S deficiency results. This effect is most pronounced on spring wheat grown under annual cropping where any residual SO_4-S has been leached into the subsoil and before appreciable mineralization has occurred. Winter wheat grown on fallow is not likely to be S deficient because of the adequate supply of SO_4-S mineralized during the fallow and the development of roots during the fall into the subsoil where SO_4-S has accumulated. Under these conditions, the crop is supplied with an adequate supply of SO_4-S. Spring wheat planted on fallow does not have the immediate advantage of an adequate supply near the soil surface, because much of the SO_4-S mineralized during the fallow season has been moved into the subso l by the winter rain. Under these condi ions, a temporary S deficiency occurs, this results in a vegetative response that is alleviated when the roots reach depths enriched in SO_4-S, or when mineralized S becomes available. Often these vegetative responses do not affect grain yields.

Leggett and others (*27*) conducted fertility experiments in Washington wherein P was included as a variable at 22 locations on fallowed ground

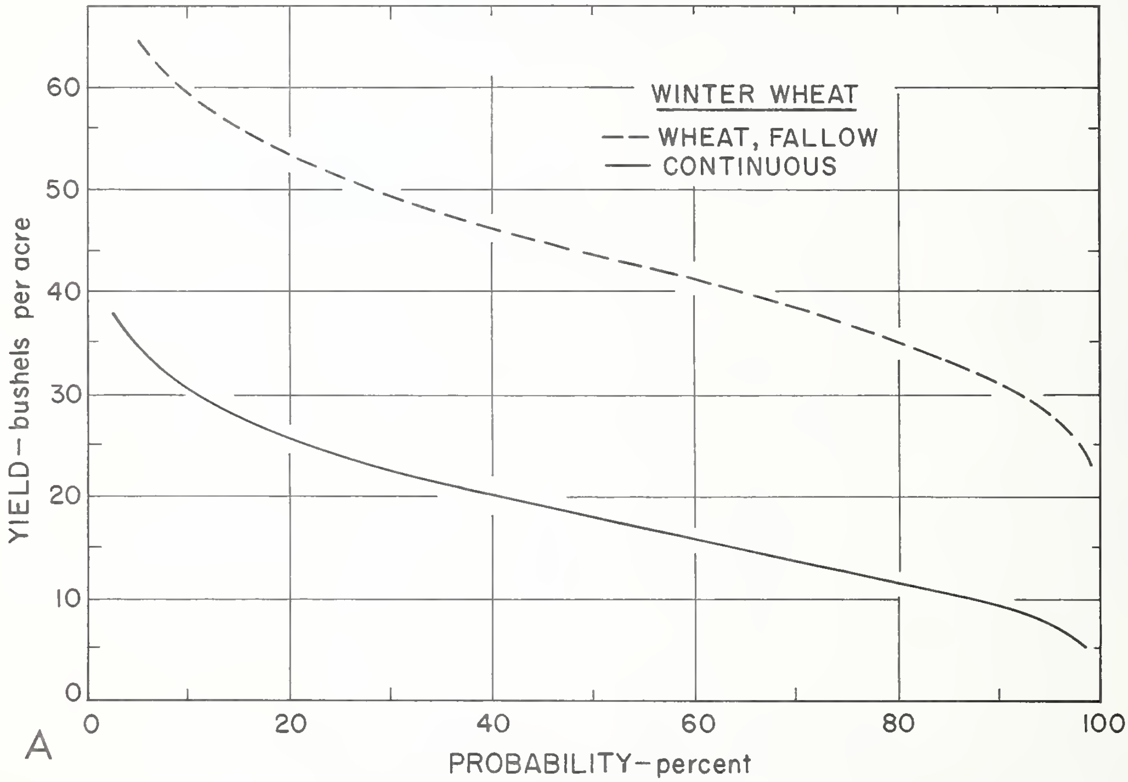
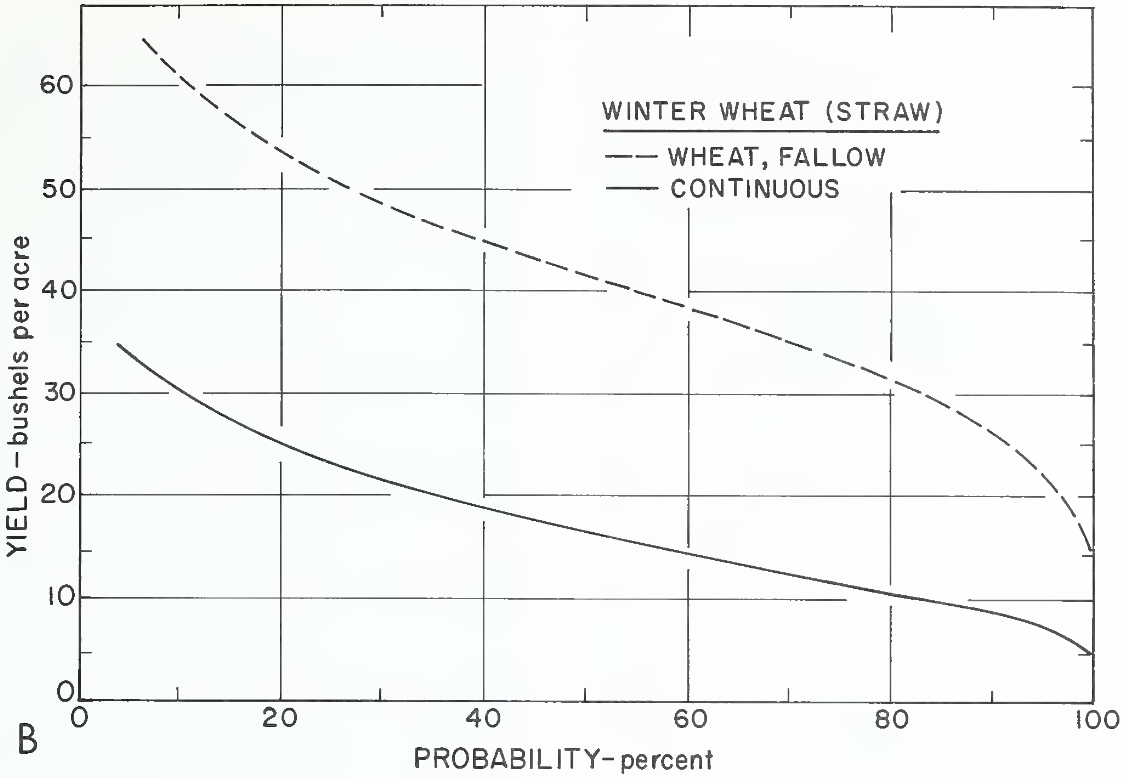
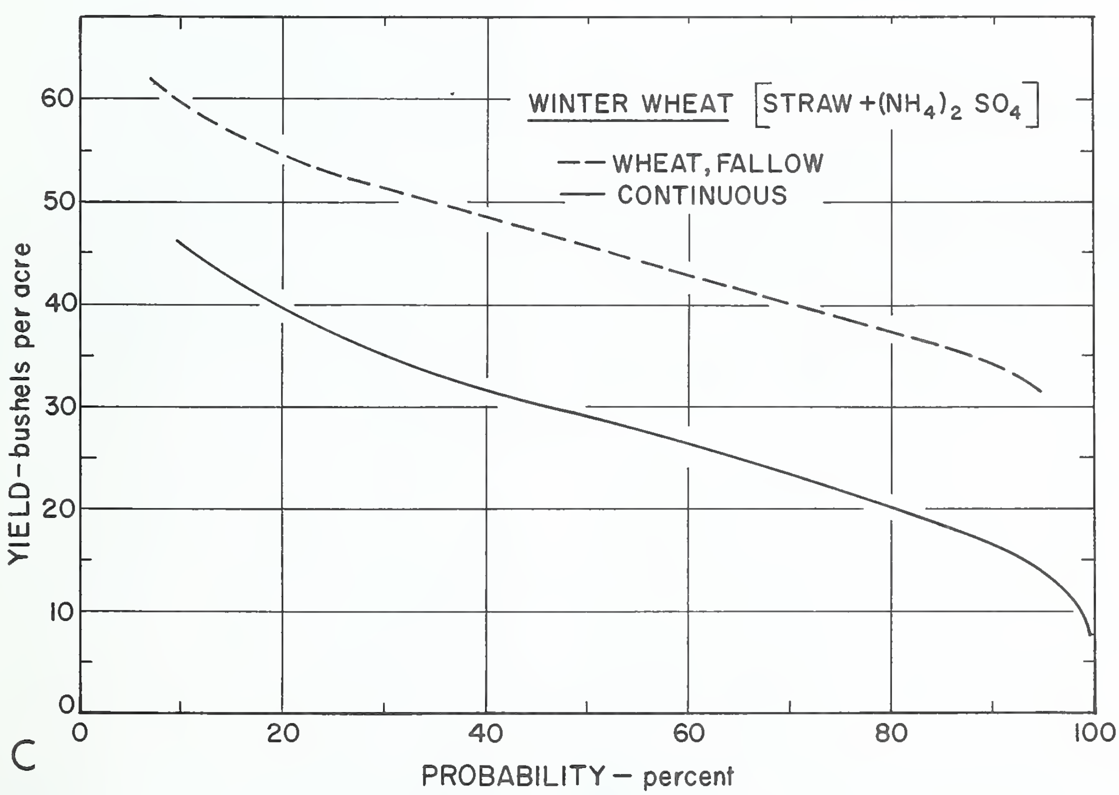


Figure 6.8.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at Pullman, Wash., 1922–45: *A*, Without amendments; *B*, with straw applied; *C*, with straw plus 60 pounds of N per acre as $(NH_4)_2 SO_4$ applied.


WINTER WHEAT (STRAW)
WHEAT, FALLOW
CONTINUOUS
YIELD - bushels per acre
PROBABILITY - percent
0
10
20
30
40
50
60
0
20
40
60
80
100

B


WINTER WHEAT [STRAW + $(NH_4)_2$ SO_4]
WHEAT, FALLOW
CONTINUOUS
YIELD - bushels per acre
PROBABILITY - percent
0
10
20
30
40
50
60
0
20
40
60
80
100

C

and 14 locations under annual cropping during the period 1953–57. No yield responses were obtained at these locations. Soil test values for available P indicated adequate levels at all locations tested. These experiments were located in areas selected for uniformity and consequently did not include sites where loss of surface soil had been prominent. Later, Guettinger and Koehler (8) showed extremely low available P in samples from severely eroded hilltops in eastern Washington. Large yield increases resulting from P fertilization have been obtained on these hilltops. Similar results were obtained in 12 of 15 experiments on fallowed and annually cropped areas in northern Idaho (*2*). In Oregon, yield responses occurred at seven sites and may have occurred at 4 others of 173 experiments conducted during 1954–57 (*16*). No data were given relating these results to soil tests for available P.

A comprehensive study of the P status of dryland soils was conducted in northern Utah. These studies involve soil test correlations for available P in both surface and subsoils, with the results of greenhouse and field experiments. A preliminary report of these studies has been published (*37*).

Water-Use Efficiency

Grain production can be influenced by water conservation, fertilization, seeding date, seeding rate, and disease and pest control. The water available for use by the crop in dry-farmed regions is determined predominantly by the climate of the region and the water-holding characteristics of the soil. Water-use efficiency as used here is defined as the yield of grain, in bushels per acre, divided by the inches of annual precipitation for annual cropping; and as the yield, in bushels per acre divided by the precipitation of the fallow year plus the crop year for a crop on fallow.

Grain production as related to water consumption and N supply on dryfarmed land is interesting and of critical importance. If the plant water supply is sufficiently limited, no grain is produced and the water-use efficiency expressed on the basis of grain is zero. With additional water, grain production begins and water-use efficiency increases rapidly if all nutrient requirements are met until the water supply is adequate to meet the evapotranspirational (ET) demands set by the environmental conditions. The latter situation usually occurs in humid regions, and the proper balance of fertilizer will give large increases in yield and in water-use efficiency, with little or no effect on water use. Conversely, under semiarid climates, excessive fertilizer can result in early depletion of the available water. If the grain crop depletes the available water supply at a critical stage of growth, reduced yields, crop quality, and water-use efficiency result. Thus, the fertilization of the crop needs to be balanced with the water supply at hand; in low rainfall areas, low rates of nitrogen fertilization generally are needed to make the most effective use of the available water supply.

Using data from 57 experiments conducted on fallowed land and 33 on annually cropped land, Leggett (*25*) developed an equation relating water supply and wheat yield under dry-farming conditions in eastern Washington. Over the range where water was limiting yield, $Y = 5.8\ (ET - 4)$ where Y is grain yield in bushels per acre and ET is the change in stored soil water present after April 1 of the crop year plus the rainfall from April 1 until wheat harvest. This equation indicates that about 4 inches of water are required to grow a crop to where actual grain production begins and that for each inch of water above 4 inches, grain production increases about 6 bushels per acre. These data represent the maximum water-use efficiency obtained from each experiment. The relation applies equally to wheat grown under fallow and to that grown under annual cropping in the area of 8 to 20 inches of annual precipitation. It is used widely for predicting yield potentials in eastern Washington by substituting expected values for available water in the equation and calculating the expected yields. From these data and the relation between nitrogen supply and wheat yield, nitrogen fertilizer needed to balance expected water supply can be applied with resultant good water use.

A similar equation relating wheat yield and water use was developed by Massee and Siddoway (*32*) for spring wheat in southeastern Idaho. Under the conditions of this area, however, wheat yield increased by 2.5 bushels per inch above a threshold value of 4.5 inches to begin grain production.

In the semiarid to subhumid regions, water-use efficiency increases with increase in water supply, especially when the water-use efficiency is expressed in terms of grain harvested. Approximately one-half or more of the total dry-matter production is vegetative material other than grain. Once the vegetative part of the plant is produced, all additional amounts of water give marked increases in grain yield. It is this relation between the yield of grain and available water that makes the storage of an additional inch or two of water in the soil during the fallow period so important in dry-farmed areas.

The influence of fallow, annual cropping, and rates of nitrogen fertilizer on the water-use efficiency of wheat in the Northwest is presented in table 6.11. Wheat grown after fallow had a lower water-use efficiency than wheat grown after wheat at all locations reported where annual precipitation was greater than 12 inches. Where annual precipitation was less than 12 inches, water-use efficiency was essentially the same for wheat grown under fallow or annual cropping.

Where annual precipitation was greater than 12 inches, application of nitrogen fertilizer increased the water-use efficiency on both fallow land and annually cropped land. When annual precipitation was less than 12 inches, application of nitrogen fertilizer tended to increase water-use efficiency, but the increases were small under both systems.

Crop Quality

Protein content and test weight are two common criteria for assessing wheat quality. Both hard and soft wheats are grown in the Northwest. Hard wheats may be sold at a premium for bread flour, provided the protein content is greater than 12 percent. Soft wheats are used primarily for pastry flour and require less than 9 percent protein. If these protein requirements are not met, the wheat is usually used for feed, and consequently brings a much lower price. High test weight, usually associated with large plump kernels, is desirable for both wheat types.

Although variety, yield, and weather influence protein content and test weight of wheat, management practices involving the use of nitrogen fertilizer and cropping system may be practical means for controlling quality. Most of the nitrogen used by a plant goes into the production of protein. When inadequate nitrogen limits crop yield, a small application of nitrogen fertilizer results in a yield increase without affecting the protein content of the grain. If more nitrogen is applied than required for max-

TABLE 6.11.—*Influence of fallow, annual cropping, and rate of nitrogen fertilizer on the water-use efficiency of wheat*[1] *in the Northwest*

State and location	Years	Average annual precipitation	Nitrogen applied	Water-use efficiency [1] of wheat after— Fallow	Wheat	Reference
		Inches	*Lb./A.*	*Bu./in.*	*Bu./in.*	
Washington:						
Lacrosse	1948–51	15.40	0	1.1	1.1	(*22*)
			30	1.3	1.8	
			60	1.5	2.5	
Dusty	1953–57	12.28	0	1.6	---------	(*26*)
			30	1.8	2.2	
			60	1.9	2.5	
Harrington	1953–57	11.57	0	1.7	---------	(*26*)
			30	2.0	2.0	
			60	2.0	2.0	
Ritzville	1953–57	11.30	0	0.9	---------	(*26*)
			20	1.1	1.2	
			40	1.0	1.2	
Idaho:						
Tetonia [2]	1955–61	13.59	0	0.7	1.1	(*32*)
			40	0.7	1.2	

[1] Spring wheat at Tetonia, winter wheat at all other locations.

[2] Water-use efficiency is the yield in bushels per acre divided by the fallow year plus crop year precipitation for wheat after fallow and by the crop year precipitation for wheat after wheat.

imum yield, the excess nitrogen will increase the protein content of the grain; the greater the yield, the more nitrogen required to alter the protein content. Thus, in low rainfall areas, where yields are not high, a few pounds of excess N markedly increases the grain protein. Increases obtained in this manner can be economically important.

Jackson and others (*20*, *21*) in Washington increased the protein content of hard red wheat 2 to 3 percent by applying nitrogen fertilizer. This was of benefit where the protein content of unfertilized wheat was at least 10 percent. Milling and baking tests showed that the extra protein produced as a result of fertilization was of the same quality as that produced without fertilization. Thus, if the protein content of bread-type wheats is increased to acceptable levels by nitrogen fertilization of varieties capable of producing good-quality protein, the crop's value is enhanced.

In southeastern Idaho, where hard red wheat is grown almost exclusively, fertilization similarly increased the protein content and thus thereby the quality and value of the crop (*7*, *47*).

A high protein content of pastry-type wheat is not desirable; thus, overfertilization should be avoided. Hunter and others (*17*) summarized results obtained with pastry-type wheats in Oregon. Where fall-applied nitrogen increased wheat yields, unfertilized wheat contained less than 9 percent protein in 88 of the 95 experiments. Wheat fertilized with the amount of N needed to produce the maximum yield (the amount required varied among the experiments) contained less than 9 percent protein in 70 of the 95 experiments. Protein was increased with each increment of added N where (a) yields were not affected (20 experiments), or (b) where yields were decreased as a result of nitrogen fertilization (16 experiments) or (c) where excess nitrogen was applied.

From these studies, it may be concluded that for the production of desirable, low protein, soft white wheat, care must be exercised to keep the nitrogen balance such that maximum yields are obtained without increasing the protein content to undesirable levels. For hard red wheats, both maximum yields and high protein are desirable; therefore, the balance between proper nitrogen fertilization rate and available water is not so critical, although excessive fertilization can result in lowered test weight.

Just as the yields of wheat are greater on fallow than under annual cropping in the semiarid area, the test weight per bushel is usually also greater for wheat grown on fallow than under annual cropping. If the wheat crop is in stress as maturity proceeds, the grain will shrivel. Generally, when yields are increased by nitrogen fertilizer, the test weights are also increased; when nitrogen has no significant effects on yield, test weights decline slightly; and when nitrogen reduces the yield level, test weights may decrease greatly.

Summary and Conclusions

Summer fallow is used in many areas of the Northwest where it is neither essential nor desirable as a conservation practice. Under average climatic and soil conditions, fallow is not needed to grow economic crops where the average annual rainfall exceeds about 16 inches. But, because of year-to-year fluctuations in precipitation and its effectiveness and our inability to accurately predict long-range weather conditions, summer fallow is often used as a safety margin to insure against uneconomic yields in areas suitable for annual cropping. Furthermore, wheat yields are higher after fallow than under annual cropping, even in areas where rainfall is adequate for successful annual cropping or on soils of limited depth where one year's precipitation usually fills the profile. Thus, the practice is attractive to farmers, especially in the 13- to 18-inch rainfall areas where it is used on so-called "set-aside" acres.

The primary objective of fallow should be to store water and under certain conditions to control weeds or other pests. Because of the destructive nature of the system, it should be used only where annual cropping is not an economical practice. Full use should be made of all crop residues to prevent undue depletion of soil organic matter and the nutrients contained therein. Under no conditions should fallow be used directly as a means for supplying nutrients through mineralization of soil organic matter. The fertility needs of the dryland areas are generally known, and needed nutrients can be supplied economically as fertilizer. The use of all residues, especially when left on the soil surface, also aids in minimizing soil and water losses through runoff and erosion. The advantages and disadvantages of the grain-fallow farming system are:

Advantages

1. Increases soil water storage
2. Has stabilizing influence on yields
3. Controls weeds, disease, and other pests
4. Provides conditions for early seeding of winter cereals
5. Decreases stubble residue at seeding time
6. Releases nutrients by mineralization

The first two advantages listed are especially important in areas where fallow is essential. Indeed they form the basis for the grain-fallow farming system. The others are advantages common to all areas where fallow is used; they may be more important in some areas or years than in others.

Disadvantages

1. Promotes inefficient use of total precipitation
2. Enhances erosion
3. Accelerates destruction of soil organic matter and loss of nutrients
4. Enhances formation of seepage and salty spots

The first three disadvantages listed are probably common to all areas where fallow is used, at least in some years. The development of seepage or salty spots depends on water movement below the root zone, relief, and underlying material.

In the Northwest, the choice of crops as alternatives to the grain-fallow system is extremely limited, even in the high rainfall areas. July and August are usually hot and dry. Significant rains are not likely to occur before late September when frost is also expected. Hence, a successful alternative crop cannot depend on rainfall after June, and therefore must reach maturity by the time the available soil water is depleted. A crop that can withstand short periods of drouth and then flourish when rain comes does not suffice in this area, because of the abrupt end of the growing season at the end of the extended dry period. The most successful alternative crops used in the area are spring and winter cereals, green or dry peas, and in some areas, alfalfa.

Thus, with a limited selection of crops, a limited effective growing season, and uncertainties in the weather, farmers make decisions that sometimes are contrary to proved conservation practices because of economic advantages. For example, annual cropping, where feasible, is preferable to grain-fallow with respect to erosion control and utilization of precipitation. This farming system however, may not provide the farmer with so high an income as can be obtained under a grain-fallow system, even in areas where annual cropping yields are at a profitable level. Hence, because of the few choices available and because of economic expediency, more fallow is used than is desirable in many of the dry farm areas of the Northwest.

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CHAPTER 7.—SUMMER FALLOW IN THE SOUTHWEST

R. E. Luebs [1]

The States of California, Arizona, Nevada, and part of Utah comprise the Southwest as used in this report (fig. 1.8). The part of Utah included is that area south of an imaginary line extending from the southern Wyoming boundary to Nevada. According to the 1964 Census of Agriculture (*22*, *23*, *24*, *25*), the 1967 Soil and Water Conservation Needs Inventory (*1*, *5*, *18*, *26*) and other published (*17*) and unpublished data, most of the summer fallow in the Southwest is in California and Utah.

Large acreage differences between the 1964 Census and the 1967 Inventory were reconciled by inquiry on an individual county basis before estimating current totals for the States. Dryland fallow for 1970 is estimated at 701,000 acres in California and 143,000 acres in the area of Utah included. Estimates for Nevada and Arizona are 300 acres each. Larger areas of fallow for weed control on irrigated land are estimated for the latter two States where, generally, the climate is too arid for dryland farming even with the summer-fallow practice. Some land is fallowed for range seedings in Nevada. No further reference to Nevada and Arizona will be made. The fallow acreage in the Southwest is a relatively small part of the total fallow acreage in the 17 Western States. Because of climatic differences between California and Utah, and their effect on dryland agriculture, fallow in these States are discussed separately.

California [2]

Introduction

Summer fallow has been practiced in California for at least 60 years. In 1916, Madson (*15*) attributed an 80 percent decrease in wheat production over the previous 10 years to the deleterious effect of continuous cropping. As a result of decreasing yields, the practice of summer fallow was advocated. Acreages of summer fallow on dryland in California are shown in figure 1.2.5, (based on the 1964 Census of Agriculture (*23*)). Current estimates of acreages (based on 1967 data of the Conservation Needs Inventory (*5*) and a 1970 survey by the author) are less than those shown in figure 1.2.5. Summer-fallow acreage in California has been gradually decreasing with time (*23*) in contrast to the increase for the Western States as a whole (fig. 1.1). Expanded irrigation, most recently in the San Joaquin Valley, has been largely responsible for the decreased summer fallow in California. Of the 58 California counties, 24 have more than 5,000 acres in summer-fallow annually. The largest area of continuous acreage on which fallow is practiced totals approximately 125,000 acres; most areas are much smaller.

Because soils and climate vary considerably, California is divided into five areas for discussion purposes. The northeastern area includes 28,000 acres of summer fallow, which are in area 21 land resources Region D (fig. 7.1). Fallow totalling 200,000 acres is located in the Sacramento Valley area which includes land resource areas 17 and 18 of Region C, north of Davis, Calif. A total of 161,000 acres are estimated for the San Joaquin Valley (areas 17 and 18) south of Davis. Most of the 224,000 acres in the central coast area are in the Central California Coast Range resource area with a small part in the northwest section of area 20. The south 88,000 acres of fallow are within the Southern California Coastal Range and the Southern California Mountains resource areas with the greater part in the latter. Over 30,000 acres of irrigated land are fallowed in California.

Climate

California's climate can be described as a dry, mild winter or Mediterranean type. Rainfall during

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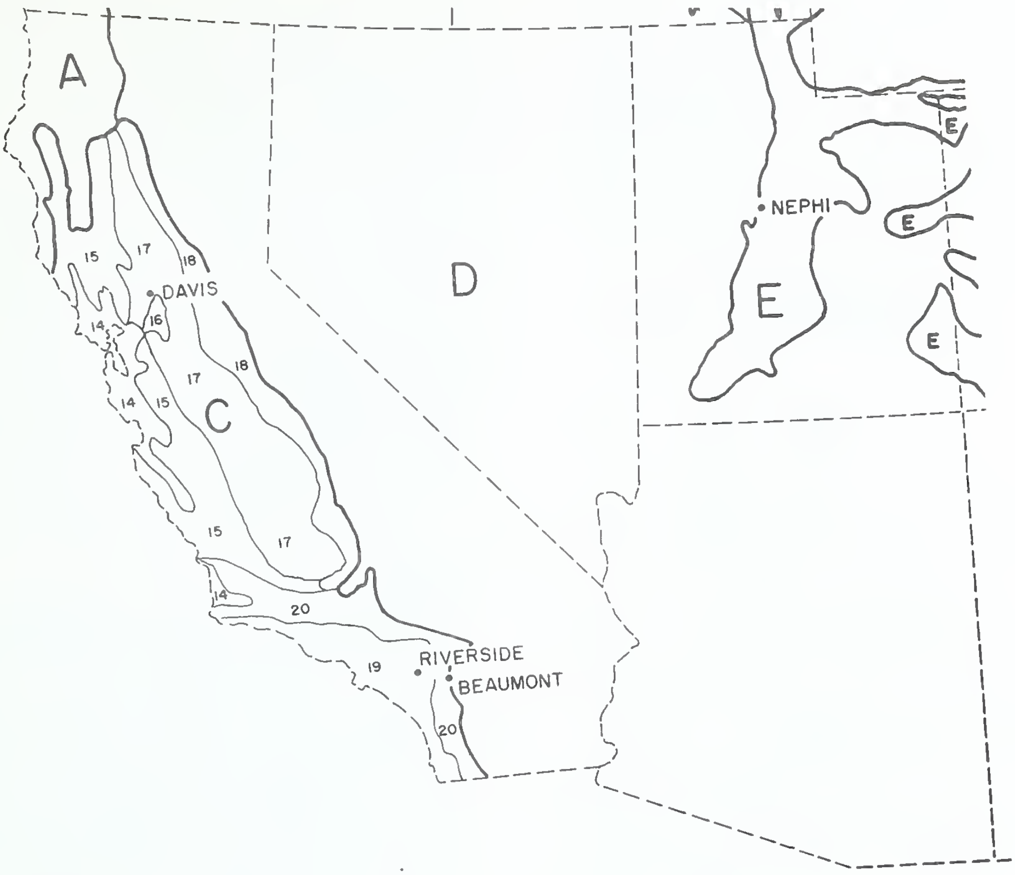
[2] The comments and suggestions on this section by John D. Prato, extension agronomist, University of California, Davis, are gratefully acknowledged.



LAND RESOURCE REGIONS AND MAJOR LAND RESOURCE AREAS

A. Northwestern Forest, Forage, and Specialty Crop Region.
C. California Subtropical Fruit, Truck, and Specialty Crop Region.
D. Western Range and Irrigated Region.
E. Rocky Mountain Range and Forest Region.

FIGURE 7.1.—Land resource regions and major land resource areas (and locations referred to in text) in the Southwest (*2*).

December, January, February, and March account for 50 percent of the annual amount in the northeast to 75 percent in the south. For over 90 percent of the area where dryland fallow is practiced, rainfall during this 4-month period ranges between 65 and 75 percent of the annual total.

Summer-fallow areas in California receive an average of 8 to 20 inches of precipitation annually. In the Sacramento Valley and in a part of the central coast between 15 and 20 inches is recorded. Except for small isolated areas, less than 15 inches on the average is received in other summer-fallow areas. Snowfall may be a significant source of water only in the northeast.

Variability of annual precipitation in summer-fallow areas is high in all areas but the northeast. According to Hershfield (*9*), the coefficient of variation of annual precipitation is between 35 and 45 percent for all dryland areas except the northeast, where it approximates 20 percent. Within-season variation in rainfall is also great. An analysis of 40 years of rainfall data at Riverside revealed less than one-half inch total precipitation during one of the four major rainfall months each year. The probability for this occurrence any one year was the same for each of these months. Insignificant amounts of precipitation occur in all dryland areas from June to September, inclusive. Except for the northeast, where freezing temperatures are limiting, the dryland growing season is determined largely by the seasonal rainfall distribution.

Soils

The largest acreage of summer-fallowed soils in California are classified as Haploxeralfs (Noncalcic Browns). Most of the fallowed soils in the Sacramento, San Joaquin Valley, central coast, and southern areas are in this group. Lesser acreages in these areas are classified as Palexeralfs (Noncalcic Browns) and Durixalfs (Noncalcic Browns). Soils classified as Haploxerolls (Chestnut and Brown soils) and Argixerolls (Brunizems) are also fallowed in the Central California Coast Range area. Argixerolls with less acreages of Haploxerolls are summer fallowed in the northeast.

Fallowed California soils range in texture from sandy loam to clay. Approximately 55 percent of these soils are fine textured, 35 percent coarse textured, and 10 percent medium textured. In the northeast, loams, sandy loams, and clay loams are fallowed, but clays and clay loams predominate in fallow areas of the Sacramento Valley. Most of the fallowed soils in the San Joaquin Valley are of a coarse texture—sandy loam and loam. However, on the west side of the north end of the valley, where dryland farming is practiced, clay and clay loam soils are commonly fallowed. Sandy loams and clays are both fallowed in the central coast. Most of the fallowed land is on sandy loams in the south.

Approximately 40 percent of the California fallowed soils are deeper than 3 feet; 50 percent are moderately deep; and 10 percent are less than 2 feet deep. The shallow soils occur primarily in the northeast and on the east side of the north end of the Sacramento Valley. Approximately 80 percent of the moderately deep dryland soils are found in the Sacramento and San Joaquin Valleys. Over 60 percent of the deep soils are in the Central Coast area.

Approximately 80 percent of the fallowed land in California has a slope of over 5 percent. One-half of the fallowed land has a slope of 10 to 25 percent, and 15 percent has a slope of over 25 percent. More than one-half of the fallowed land with slopes between 10 and 25 percent is in the Central California Coast Range area. Slopes of over 25 percent occur at the northern ends of the San Joaquin and the Sacramento Valleys. Slopes of less than 5 percent predominate in the northeast. Forty percent of the fallowed lands in the south and 20 percent in the San Joaquin Valley have relatively gentle slopes.

Crops and Cropping Practices

Barley is the principal crop for which land is fallowed in California. Approximately 65 percent of the fallowed land is planted to barley and 35 percent to wheat. Relatively more wheat is grown in the northeast, central coast, and south than in the Sacramento and San Joaquin Valleys. The distribution of barley and winter wheat acreage harvested in California as shown in figures 1.5 and 1.7 includes irrigated acres; hence, distribution of these crops on dryland after summer fallow is not satisfactorily depicted. Spring varieties of wheat and barley are grown almost exclusively in California. However, since most of the acreage is planted in the fall, California spring varieties have sometimes been called winter wheats. Apparently this accounts for the acreage of winter wheat shown in figure 1.5 and the absence of any spring wheat acreage in figure 1.6. Dryland cereal crops are planted after fallow for grain production. However, severe drought results in a small acreage, probably less than 5 percent as an annual average, being harvested for hay or used for grazing.

The 2-year fallow-crop system is used on all, except possibly 15 percent, of the dryland grain acreage. In the northeast a fallow-crop-crop rotation is practiced on approximately one-half of the drylands. Rotations, including pasture, fallow, and grain, in that order, are found in the Sacramento Valley, San Joaquin Valley, and the south. More than 1 year of pasture is used in the northern end of the Sacramento Valley.

Except for later maturity in the northeast, the grain crop matures in June or early July and is harvested during the following 2 or 3 months. Most of the California summer-fallow land is initially tilled in February to April of the year after harvest. Volunteer grain and other annuals grow during the winter under this fallow system. However, some of the acreage in the central coast, the San Joaquin Valley, and the south is rough tilled in the summer or fall after harvest. This is followed by two operations with the plow or disk during February through June. Subsequent light disking or rod weeding operations are carried out for weed control. Generally, there is a maximum of two of these weeding operations. Harrowing or light disking just before planting in November or December completes the fallow operations. Ideally, the seedbed is prepared after initial fall rains so that operations also eradicate recently emerged weeds. A considerable acreage may be seeded into dry soil if early season rainfall is light or absent. Grazing volunteer grain during the winter is common in some areas.

A typical time sequence for operations from harvest to harvest on a large acreage follows:

Time	*Field operations and conditions*
June or early July	Harvest wheat
July through February, March, or April	Stubble and volunteer growth
February through April	Initial tillage
April through October or November	Cultivate fallow
November or December	Plant wheat
November or December through May or June	Wheat growth
June or early July	Harvest wheat

Water Conservation

Few measurements of water-storage efficiency of the summer-fallow practice have been made in California. In 1911, fallow was recognized as a water-conservation practice by Shaw (*21*). Sixty years later, Luebs and Laag (*14*) reported fallow-efficiency data for a Hanford sandy loam in the south. In their studies, most of the runoff was retained with dikes at 25-foot intervals on a 2- to 3-percent slope. The average fallow period was 16.5 months and extended from the previous grain harvest to just before the first significant rainfall of the growing season. Average rainfall over the fallow period was 13.9 inches of which an average of 2.2 inches was stored in the 6-foot depth of soil (table 7.1). Water-storage efficiency ranged from 13.1 to 23.6 percent and averaged 16.7 percent for a 4-year period. Drainage by unsaturated flow from the 6-foot soil depth during the fallow period was indicated. Finer textured soils with greater water-holding capacity would permit less loss from unsaturated drainage, which should result in higher water-storage efficiency.

With continuous cropping, a fraction of an inch of rainfall occurring just before tillage for planting usually is the only available soil water between the previous harvest and planting. Therefore, water conserved by the fallow practice is the approximate difference in water stored between the two systems. The rainfall season begins earlier in the fall as distance to the north increases; hence, significant soil-water storage probably occurs in some areas during the few weeks just before planting.

Erosion

Wind

Wind erosion is generally not a problem on fallow lands in California. However, it is a severe problem in localized sections of the south and particularly in the Southern California Mountains resource area. Severe soil blowing has also been reported on fallow in the Central California Coast Range area. In these locations, stripcropping (alternating cropped and fallow strips of land across the direction of the prevailing winds) is effective in reducing wind erosion. Apparently no research data are available in these areas for this or other control methods. In the south, it is common for soil blowing to occur on bare fallow lands for 1 or 2 days several times during the winter.

Water

Water erosion of soil from fallow land is frequently severe in California. The tendency for several closely spaced storms to occur during the rainfall season is conducive to runoff and erosion.

TABLE 7.1.—*Efficiency of fallow for water storage on Hanford sandy loam*

Fallow period	Rainfall	Water stored [1]	Efficiency of storage
	Inches	*Inches*	*Percent*
1965–66	12.7	3.0	23.6
1966–67	12.2	1.6	13.1
1967–68	10.0	1.7	17.0
1968–69	[2] 20.6	2.7	13.1
Average	13.9	2.2	16.7

[1] 6-foot soil depth.
[2] Approximately 6 inches were lost as runoff.

The relatively steep slopes of summer fallow land also contributes to the erosion problem. Donnelly (*6*) analyzed the monthly rainfall distribution in the south; and, of the six types of rainfall seasons that can be expected, one in particular results in severe soil erosion by water. This is the "elongate-peak" season, when more rain falls in a single month than in the rest of the months combined. According to Donnelly's analysis this type of distribution can be expected 15.4 percent of the time.

The effects of water erosion on California hill soils have been pictorially illustrated by Weir (*28*); however, data on the magnitude of erosion apparently are not available. Donnelly and coworkers [3] measured soil losses on dryfarmed bean land in the southern California coastal area. Data were obtained for a Tierra clay loam with a slope of 18 percent and an Altamount loam with a slope of 36 percent. Average annual soil losses with bare fallow were 62 and 37 tons per acre for the Tierra and Altamount soils, respectively. Over the 5-year period of study, 1940 to 1944, the maximum annual loss was 129 tons per acre on the Tierra clay loam.

Data on the effect of tillage on water erosion of soils in California has not been obtained. However, Donnelly and coworkers [3] found that a cereal-straw mulch reduced soil losses from 21 to 1 ton per acre on the Altamount loam and from 17 to 1 ton per acre on the Tierra clay loam.

Soil Fertility

Total Nitrogen and Organic Carbon

California mineral soils are relatively low in total nitrogen content. The 0- to 6-inch layer of several soils in the south where dryland fallow has been practiced averaged 0.05 percent nitrogen (*12*). Samples taken from an area farmed over a 70-year period, mostly by the fallow-grain system, and an adjacent area that had never been cropped were analyzed for organic carbon. Assuming that organic carbon multiplied by 0.085 approximates the total nitrogen, total N decreased from 0.065 percent to 0.046 percent in a Ramona sandy loam and from 0.074 percent to 0.043 percent in a Placentia sandy loam as a result of 70 years in the fallow-crop system. Using the same calculations, Martin and Mikkelsen (*16*) found in the central Coast that total N was 0.18 percent in a soil cropped 2 years; whereas, with 75 years of fallow-cropping, total N was only 0.07 percent.

Organic carbon content in the 0- to 6-inch increment of the Ramona sandy loam in the south was 0.77 percent for the noncropped land and 0.54 percent after 70 years of fallow-grain cropping (*12*). For the Placentia sandy loam, the data showed 0.87 percent for no cropping and 0.51 percent for fallow-grain cropping. Assuming a factor of 0.59 for converting organic matter to organic carbon, an essentially noncropped soil of the central coast contained 2.1 percent organic carbon (*16*). Adjacent soil fallow-cropped for 75 years contained 0.80, or about the same as soils in the South with no previous cropping.

Studies comparing the fallow-crop system with other cropping systems for their effect on organic carbon and nitrogen in the soil apparently have not been made on California soils. Also, the effect of fallow on the total phosphorus content has not been ascertained.

Available Nitrogen

Fallowing increases the supply of available soil nitrogen. The importance and magnitude of this effect are frequently overlooked, where soil-water storage from relatively low rainfall is considered the chief purpose for fallowing. At Riverside, soil samples from the 0- to 6-inch depth taken in 1968 from plots fallowed 18 months contained an average of 48 p.p.m. nitrate-nitrogen, but samples taken from continuous-cropped plots contained 9 p.p.m. The following year, after a 16-month fallow period, the 0- to 6-inch layer contained 31 p.p.m. and the 6- to 12-inch layer contained 5 p.p.m. In continuously cropped plots, nitrate-nitrogen averaged 8 and 2 p.p.m., respectively.[4]

Increased nitrogen availability with fallow is also inferred from extensive fertilizer trials conducted in California by Martin and Mikkelson (*16*). They evaluated response to nitrogen fertilizer by barley grown continuously and by the fallow-crop system. Apparently, cropping systems were not compared at individual test sites. Where annual rainfall

[3] Donnelly, Maurice, W. H. von Trebra, and W. W. Weir. conservation of bean land in south coastal california. (Unpublished.) 1945.

[4] Luebs, R. E. annual research reports. Agr. Res. Serv. U.S. Dept. Agr. Riverside, Calif. 1966–67.

averaged 16 inches, 15 of 17 tests with continuous barley showed a statistically significant yield increase from nitrogen application. After fallow and in an area averaging 14 inches of rainfall, the yield response to applied nitrogen was significant in 5 of 18 tests. The average yield increase of continuous barley from 45 pounds of nitrogen was 13 bushels per acre. This compares with an average increase of 4 bushels for the fallow-cropped barley. Barley after fallow often exhibits vigorous growth and dark green color, which is apparently more from increased nitrogen availability than from increased soil-water storage. However, nitrogen fertilization (in addition to that mineralized during fallow) is needed in some cases for maximum yields. Applications of low rates of nitrogen after fallow have been increasing in the Sacramento Valley and the northeast.

The increased nitrogen availability after fallow is a significantly favorable effect for grain yields where annual rainfall is over 12 inches. However, where annual rainfall is less than 10 or 12 inches, this increased nitrogen availability may limit grain yield to a small degree. Data of Luebs and Laag (*13*) showed that increased vegetative growth can exhaust the soil water early in the season, resulting in plant water stress at a later time when evapotranspiration potential is high and the rainfall season has ended.

Available Phosphorus

The effect of fallow on phosphorus availability in California soils has not been intensively studied. Martin and Mikkelsen (*16*) analyzed a wide range of soils for available phosphorus before planting in the continuous cropping and the fallow-crop system. Both water soluble and bicarbonate extractable analyses were made. The supply of available phosphorus apparently could not be related to the cropping system.

Crop Yields

Increases From Fallow

Crop yields are markedly increased by fallow in California. With no fertilizer application on a silt loam at Davis, Calif., Madson (*15*) reported over a threefold increase in average wheat yield for fallow (35.3 bu./A.) as compared with continuous cropping (11.4 bu./A.) over the 4-year period 1910 to 1913. The large advantage in grain yield with the fallow practice explains the wide use of fallow in dryland agriculture over the past 60 years.

Data obtained by Luebs and Laag (*14*) near Riverside, Calif., suggest that the yield difference between continuous cropping and the fallow-crop system may be less with nitrogen application. Nitrogen was applied at what was considered to be optimum levels for the particular season. The fallow-crop system increased the average barley grain yield 55 percent over continuous cropping for a 4-year period with no runoff control (table 7.2). No yield difference was measured in 1966, but fallow nearly tripled the yield over continuous cropping the following year. Statistical analysis of these data, along with that for an additional cropping system (*14*), showed yield increases from fallow to be statistically significant in 1967 and 1968. With retention of most of the runoff with dikes at 25-foot intervals on a 2-percent slope, the average yield advantage for fallow was reduced from 10.2 bushels per acre to 6.3 bushels per acre. Yield increase with runoff retention on fallow was statistically significant in 1968 only.

These data suggest that with nitrogen application more barley is produced by continuous cropping because twice the land area is needed in a crop-fallow system. With runoff retention as practiced in the Riverside experiment, average annual production was 61 percent greater with continuous cropping than with the fallow-crop system.

Water-Use Efficiency

Water-use efficiency is defined here as the pounds of grain produced per inch of rainfall received since the previous grain harvest. Only limited data on water-use efficiency of fallow and other cropping systems are available in California. Findings near Riverside in the south by Luebs and Laag (*14*) show higher water-use efficiency in 3 of 4 years by continuous cropping (table 7.3). The practice of fallowing during alternate years decreased the average water-use efficiency for barley grain by 16.7 percent. These data were obtained on a Hanford sandy loam with about a 2-percent slope. Evaporation along with limited runoff and unsaturated drainage contributed to water losses during the fallow period. It appears likely that rainfall-use efficiency may be higher with continuous cropping than with the fallow system for a majority of years on sandy loam soils.

TABLE 7.2.—*Barley grain yield with runoff and runoff retention under annual cropping and the fallow-crop system*

Year	Annual cropping			Fallow-crop		
	N applied	Runoff	Runoff retention [1]	N applied	Runoff	Runoff retention [1]
	Lb./A.	*Bu./A.*	*Bu./A.*	*Lb./A.*	*Bu./A.*	*Bu./A.*
1966	40	14.5	14.5	40	14.5	14.5
1967	40	11.5	22.3	40	29.9	32.7
1968	30	19.7	21.6	0	31.8	31.4
1969	60	27.9	44.4	0	38.1	49.6
Average		18.4	25.7	------------	28.6	32.0

[1] Runoff retained with 8-inch dikes at 25-foot intervals on a 2- to 3-percent slope.

Production Stability

Production stability has probably been a major factor in the extensive use of fallow for dryland agriculture in California. The high variation in annual rainfall between seasons and within seasons, as previously discussed, reduces production stability with continuous cropping. Production stability of the continuous cropping system can likely be increased by application of nitrogen fertilizer and the retention of runoff on gently sloping lands.

Methods of Tillage

Tillage experiments with the fallow-crop system were conducted at several locations in southern California from 1945 to 1960 (*12*). Implements common to all experiments and the approximate depth of operation were moldboard plow, 8 to 10 inches; disk, 4 to 6 inches; and subtiller, 4 to 5 inches. At the two locations where yield potential was greatest (Ramona and Placentia site No. 1), presumably because of more favorable soil and water conditions, tillage method affected yield (table 7.4). Moldboard plowing yields were significantly greater than either disking or subtilling. There was no difference between the latter two methods. At the other two locations, (Arlington and Placentia site No. 2), average yields were 9.2 to 26.2 bushels less, and all tillage methods resulted in approximately the same yield. At the Ramona and the two Placentia soil sites, a 30-pound per acre nitrogen application was compared with a check (data not shown). At the Ramona site, nitrogen increased yields with disking and subtilling to a level slightly below that of plowing. A lesser effect occurred at the Placentia No. 1 site, with no effect at the Placentia No. 2 site. Limited soil-water data at the Placentia No. 1 site showed that subsurface tillage resulted in markedly greater water storage than disking or plowing in 1 year of 3. No significant difference was measured in other years.

TABLE 7.3.—*Water-use efficiency for barley in the continuous crop and the fallow-crop systems on Hanford sandy loam*

Year	Continuous cropping	Fallow-crop
	Lb /in	*Lb /in*
1966	53.1	31.4
1967	40.9	56.7
1968	92.9	64.4
1969	62.6	55.4
Average	62.4	52.0

Crop Quality

Protein Content of Grain

In the south, barley grain produced after fallow has a higher protein content than barley produced by the continuous cropping system. This might be expected from the higher nitrogen availability in the soil after fallow. Protein content was determined for grain harvested in 1968 and 1969 from the experiment reported in table 7.2. After fallow, protein content was 16.1 percent in 1968 and 16.5 percent in 1969, and with continuous cropping it was 14.6 and 13.8 percent, respectively. The fallow effect on protein content through increased soil nitrogen availability was large considering nitrogen application. None was applied after fallow, but 30 and 60 pounds were applied for continuous barley in 1968 and 1969, respectively. Where fallow is likely to reduce water stress more, as in the Sacramento Valley and the northeast, kernels may be more plump and a lower protein content may result. Lower protein content, 12 percent or lower depending on the barley variety, is required for malting. However, most of California dryland barley is used as feed for which a high protein content is desirable.

Test Weight

Test weights of dryland barley (yields reported in table 7.2) averaged slightly higher after fallow than with continuous cropping. Where normal runoff occurred, the 4-year average test weight was 38 pounds per bushel for continuous cropping and 41 pounds per bushel for the fallow-crop system. The greatest increase for the fallow system, 9 pounds, occurred in 1967, when yield was 2.6 times greater after fallow. During that year, grain samples from an area of continuously cropped plots where runoff was concentrated had a test weight slightly higher than was measured after fallow. From this it is concluded that decreased water availability decreases the test weight with continuous cropping. Test weights in the south after fallow tend to be low when compared with the standard of 48 pounds per bushel for barley. This is attributed to the frequent occurrence of water stress during grain filling.

TABLE 7.4.—*Effect of fallow tillage methods on average barley grain yields*

Soil	Years	Plow	Disk	Subtiller
		Bu./A.	*Bu./A.*	*Bu./A.*
Arlington sandy loam	4	21.7	21.2	20.8
Ramona sandy loam	3	45.2	31.7	31.0
Placentia sandy loam (site No. 1)	3	35.2	29.8	28.1
Placentia sandy loam (site No. 2)	6	19.0	19.0	19.8

Summary

Advantages and Disadvantages of Fallow

The major factor in favor of the fallow practice in California is a greater and more stable production. Not only is some water stored in the crop root zone but also available soil nitrogen is greatly increased. The ratio of available nitrogen to water is generally more favorable after fallow. Continuous cropping requires more nitrogen application for satisfactory yields. Better weed control is also an advantage of the fallow practice. If seeding in dry soil is necessary with continuous cropping because of the lack of early rains, the weed problem may be severe. Broadleaf weeds can be controlled easier by spraying than can wild oats, a winter annual. The incidence of root and crown rot disease is an important problem with continuous cropping in the Sacramento Valley and the northern part of the San Joaquin Valley. Also fallowing usually results in a somewhat better seedbed, and the cost of planting and harvesting is about one-half that for annual cropping.

The major disadvantage of fallow is soil erosion by water. The large area of moderately to steeply sloping lands that are fallowed accentuate this problem. Much of the marginal or abandoned drylands have been reduced to their present low level of productivity because of erosion. The storage efficiency of precipitation is low with fallow. Evaporation over the hot, rainless summer and unsaturated drainage in coarser textured soils result in much loss of water. In the south near Riverside, several fallow soils were wetted deeper than 4 feet and covered with polyethylene film for 5 days early in a rainless summer. The film was removed and after 12 weeks' exposure 2.4 to 4.2 inches of the water had been lost from the 4-foot depth of three loamy sand and sandy loam soils. Water-use efficiency, as measured by grain production, is usually less with the fallow-crop system than with continuous cropping provided nitrogen is applied with the latter system.

Alternatives for Fallow

Possible soil- and crop-management systems for dryland agriculture are limited. The fallow-crop system has been successful, and there are few alternatives when the potential level of income from dry-farmed lands is considered. Water and nitrogen availability for grain without fallow can be increased by applying nitrogen fertilizer and by keeping nearly all water from rainfall on the land. On the gently sloping lands, small dikes or terraces retain the runoff. On steeper slopes, maintaining crop residues on the surface retards runoff. More research is needed on storing all rainwater in the soil under continuous cropping. Also, research on overcoming disease and weed problems is needed before continuous cropping can be successful, particularly in the Sacramento Valley.

Reduction of fallow by including a year or more of seeded or volunteer pasture in the cropping system is now practiced in several dryland areas in California. Pasture follows the grain crop. Converting marginal dry-farmed land to annual pasture is another alternative. Results of a study on the establishment and production of annuals for forage on these lands in the south have been reported by Luebs and Laag (*11*). Dryland pasture of annual clover and grasses has been profitably established on land previously cropped with the fallow-grain system in the Sierra Foothill resource area of the San Joaquin Valley. Some dryland grain acreages in the northeast have been converted to wheatgrass pasture.

Utah

(Exclusive of the Panhandle Area)

Introduction

Summer fallow has been practiced in Utah for over 70 years. Dryland farming was initiated about 1870. Farmers soon found that fallowing for a year was a beneficial practice for the production of winter wheat (*9*). About 55 percent of the summer fallow acreage in Utah is in the area discussed in this report on the Southwest (*25, 26*). Six counties have over 5,000 acres each, and five counties, namely, Millard, Juab, Salt Lake, San Juan, and Utah counties have over 15,000. Except for the area in San Juan County, nearly all the fallow acreage is in resource area 47 of the Rocky Mountain Range and Forest Region (fig. 7.1), which extends in a north and south direction through the center of the State. The fallow area in San Juan County is mostly in the same land resource region, but in the southern Rocky Mountain area adjacent to the Colorado boundary in the southeast corner of the State. This fallow area of over 35,000 acres is the largest of those considered here. The annual total summer-fallow acreage in these areas of Utah has apparently varied as much as 15,000 acres from 1949 to 1971 (*2, 24, 25*).

Climate

Average annual precipitation in dryland areas ranges from 10 to 14 inches. The 67-year average at Nephi is 12.6 inches. Other major drylands in the north-central area receive an average of 14 inches per year. In the San Juan County fallow area, the average precipitation is between 13 and 14 inches.

At Nephi, where distribution is representative of the central fallow area, average monthly totals range from 0.6 inch in June to 1.5 inches in May. The major differences in average distribution between San Juan County and Nephi are: Over 77 percent more rainfall in the July through October period and 40 percent less in May in the San Juan County area. At Nephi, precipitation for the 4-month, March through June, period was most highly correlated with dryland wheat yields (*3*). Several investigators (*3, 4, 20*) have concluded that distribution is more important than total amount for wheat yields.

According to Harris and others (*9*) the frost-free period averages 110 to 150 days in dryland areas. Spring and fall frosts often damage crops. Winds are of relatively low velocity in the north-central area, rarely exceeding 30 miles per hour at Nephi. Wind velocities are higher in San Juan County.

Soils

Summer-fallowed soils in central Utah generally are classified as Argixerolls (Brunizems), Haploxerolls (Chestnut and Brown soils), or Argiborolls (Chernozems). In the San Juan County drylands of southeast Utah, fallowed soils are likely to be Argiustolls (Chernozem and Chestnut soils) or Haplustolls (Chernozem and Chestnut soils).

Most fallowed soils in central Utah are alluvial soils with a wide range of texture. At Nephi, where much fallow research was conducted, the soil is Nephi silt loam. Other central drylands have loam and gravelly loam soil. Generally, sandy loam of aeolian origin occurs in the San Juan County drylands. Land slopes range up to 10 percent in the fallowed areas in the Utah drylands. A large proportion has slopes of less than 5 percent.

Crops and Cropping Practices

Winter wheat is the major crop for which fallow is practiced although a small acreage of spring wheat is grown. Winter wheat is the best adapted and most valuable small grain crop for dryland farming in Utah. The alternate fallow-wheat cropping system is used almost exclusively where fallow is practiced.

Tillage in the fall after harvest depends on the weed infestation, amount of stubble, and soil-water content. If necessary, tillage is performed anytime after harvest. Otherwise, the initial tillage (plowing) is delayed until April of the following year. Subsequently, at least two operations with the rod weeder are used for weed control, one in the spring and one before planting in the fall. In the central area, winter wheat is planted from August to October, with the more southerly areas being planted in the latter part of the period. September planting dates are common in San Juan County. A typical time sequence for operations from harvest to harvest follows:

Time	*Field operations and conditions*
August	Harvest wheat
September through March	Stubble
April	Initial tillage
April to seeding	Cultivate fallow
August through October	Plant wheat
Seeding through July	Wheat growth
August	Harvest wheat

Water Conservation

Water-storage efficiency for fallow is relatively high in the central area and probably in all Utah dryland areas. From data reported by Bracken and Cardon (*4*) from Nephi for one sampling, average annual fallow water-storage efficiency between harvest and planting times in successive years was calculated to be 37.2 percent for the 8-year period 1909 to 1917. With a later sampling date (about November 1) and for a 7-year period (1925 to 1932), average efficiency was 33.3 percent. Soil-water measurements were made for the 6-foot depth of soil. Their data showed a net loss of soil water in 10 of 15 years between the March–April sampling and the fall sampling (near planting time). Any soil-water gains over this period were small, usually less than 0.1 inch.

Bennett and coworkers (*3*) at Nephi found that summer tillage in excess of that required for weed control was unnecessary for yield. It can be assumed that tillage did not conserve water except by eradicating weeds.

Erosion

Wind erosion is not a significant problem on fallow land in the central area of Utah. However, it occurs in the San Juan County area of southeastern Utah and is severe some years.[5] In this area, ridging of the soil is sometimes practiced to control winter wind erosion.

Water erosion occurs on fallow land, but it is not a severe problem. Two situations are associated with soil erosion by water. One is high-intensity summer storms and the other is rain or snowmelt on frozen soil. Tillage methods that leave crop residue on the soil surface (stubble mulching) would presumably aid in controlling this erosion. However, 1971 studies of Van Epps [6] show that average wheat yields are 2 to 3 bushels less with stubble mulching than with moldboard plowing, even with applied nitrogen fertilizer.

Soil Fertility

Fallowing reduces the total nitrogen content of the soil more rapidly than does continuous cropping, according to data of Greaves and Bracken (*8*) (table 7.5). Average annual losses of total soil nitrogen during the period 1918 to 1943 at Nephi were three to four times greater with continuous fallow, or fallow in 2 of 3 years, than with continuous wheat. The alternate fallow-wheat system increased nitrogen losses 75 percent more than continuous cropping. There was little difference between fallowing once in 2 years and once in 3 years.

Soil organic carbon with continuous wheat and fallow-wheat cropping increased over a 25-year period, beginning 14 years after cropping of sagebrush land was initiated (table 7.5). Continuous fallow (no crop grown for 25 years) reduced organic carbon, but the ratio of fallow to crop years in the

[5] Personal communication from Gordon A. Van Epps, associate professor of Agronomy, Utah State University.

[6] Van Epps, Gordon A. Unpublished data on the effect of follow tillage methods on wheat yield. 1971.

system was not consistent in its effect on organic carbon.

Total phosphorus losses were recorded for all cropping systems (table 7.5). Systems with fallow generally increased phosphorus losses. The average annual losses with continuous fallow and the fallow-crop system were 75 percent and 38 percent greater, respectively, than with continuous cropping.

Crop Yields

Wheat yields with the fallow-crop system average over twice those from the continuous cropping system according to Bennett and coworkers (*3*). They show an average annual yield of 23.2 bushels per acre for wheat after fallow and 9.9 bushels for continuous wheat at Nephi over the 46-year period 1904 to 1949. Maximum yields were 42.5 bushels and 24.0 bushels and minimum yields were 6.9 bushels and 2.0 bushels for wheat after fallow and continuous wheat, respectively.

The probability of obtaining a specified (or higher) yield with and without fallow can be ascertained from the data of Bennett and coworkers (*3*). The probability curves (fig. 7.2) have been constructed according to the method of Friedman and Janes (*7*). For example, the probability of obtaining a wheat yield of 10 bushels per acre or more is 96 percent with the fallow-wheat system and only 43 percent with the continuous wheat system. For yields of 20 or more bushels, the probability is 62 percent with fallow-wheat and only 5 percent with continuous wheat.

Production stability with the fallow-crop system is greater than with continuous cropping. By reversing the percentages on the abscissa of the graph in figure 7.2, it can be determined that the probability of obtaining yields of 5 bushels per acre or less with continuous cropping is 17 percent. Yields after fallow were higher every year except one over the 46-year period (*3*).

Average water-use efficiency for wheat in the alternate fallow-crop system was determined at Nephi by Bracken and Cardon (*4*). They reported

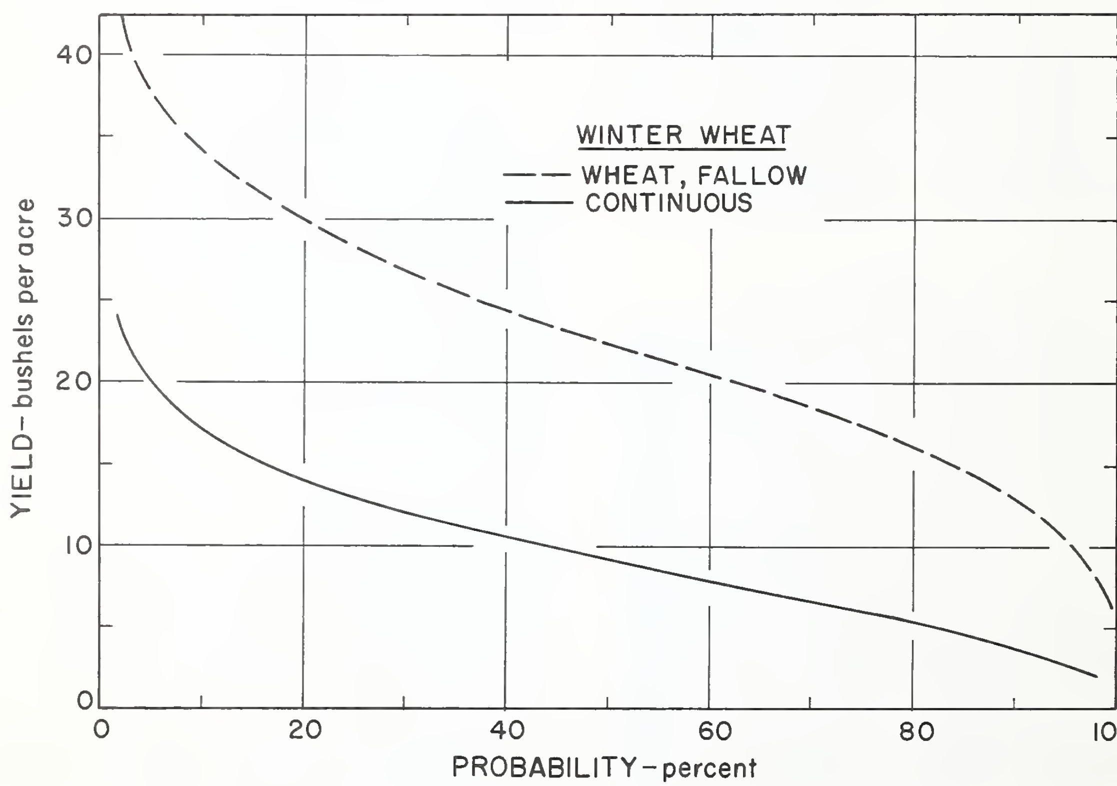


FIGURE 7.2.—Curves showing probability of obtaining a specified yield or more of winter wheat with two cropping systems at Nephi, Utah, 1904–49.

TABLE 7.5.—*Changes in total nitrogen, phosphorus, and organic carbon in Nephi silt loam with cropping system over a 25-year period (1918–43) (8)*

Cropping system	Nitrogen loss		Phosphorus loss		Organic carbon change	
	Total	Annual	Total	Annual	Total	Annual
	Percent	*Lb./A.*	*Percent*	*Lb./A.*	*Percent*	*Lb./A.*
Continuous wheat	4.4	16	1.3	16	3.2	111
Fallow-wheat	7.8	27	2.1	22	4.6	151
Fallow-wheat-wheat	8.6	30	4.7	47	−2.1	−69
Fallow-fallow-wheat	19.8	71	.5	6	<0.1	6
Continuous fallow	14.3	56	3.0	27	−5.3	−184

49 pounds of wheat per inch of water for the 1911 to 1918 period and 56 pounds for the 1927 to 1933 period.

The effect of fertilizer application on wheat yield after fallow has not been consistent. During the period 1943 to 1950, Peterson (*20*) showed an average wheat yield increase at Nephi of 7 bushels per acre from the application of 40 pounds of nitrogen. In a comprehensive study of nitrogen response in the north-central and central areas during a period of generally below-average rainfall, Nielson and Van Epps (*19*) reported a positive yield response to nitrogen in only 24 of 64 tests and a yield depression in eight tests. Yields were increased by nitrogen application in only two of seven tests in San Juan County. Yield depressions resulted from water stress in the latter part of the growing season.

Wheat grown after fallow has responded to phosphorus fertilizer, but yield increases have been small and have occurred only when nitrogen was applied. Nielson and Van Epps (*19*) reported the first yield increase from phosphorus as occurring in 1957 at Nephi.

Crop Quality

Peterson (*20*) observed in 1952 that the protein content of wheat after fallow was declining and that yellow berry, a symptom of deficient nitrogen, was prevalent in some areas. He found that an application of 40 pounds of nitrogen per acre increased protein content by an average of 2.4 percent at Nephi over a 7-year period. Nielson and Van Epps (*19*) reported that, with below-average rainfall or unfavorable rainfall distribution, protein content was more likely to be increased by nitrogen application than was grain yield. Test weight of wheat after fallow was relatively high, over 61 pounds per bushel, and not significantly affected by nitrogen application (*20*). No data comparing fallow and continuous cropping on the basis of crop quality are available.

Summary

The outstanding advantage for fallow in the area of Utah considered in this report is the large increase in yield, 134 percent for the best adapted crop, winter wheat.

A large part of this increase probably results from the relatively high water-storage efficiency of fallow, 35 percent. During average and above-average rainfall years, fallow also permits profitable yield response from the application of nitrogen fertilizer.

Soil erosion by water may be a limited disadvantage for the fallow practice. The magnitude of this erosion apparently has not been documented. Losses of plant nutrients from the soil whether by erosion or by the fallow-crop system will add to future costs of production.

There are few alternatives to the fallow practice on Utah dryland covered in this report. Beans are grown in a 2-year rotation with wheat in San Juan County. The production of crested wheatgrass for seed on dryland where rainfall averages 12 inches is an alternative to winter wheat and fallow in the central area (*27*). Dryland alfalfa and wheatgrasses are grown on limited acreages in the north-central area, where annual rainfall averages from 14 to 20 inches.

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CHAPTER 8.—GENERAL RELATIONSHIPS AND CONCLUSIONS

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The acreage of land summer fallowed in the Western United States has steadily increased from about 5 million during 1910 to 1914 to about 37 million in 1967. According to the 1964 Census of Agriculture the greatest concentrations of fallow for the 17 Western States were in North Dakota, Kansas, and Montana, each with 6 to 7 million acres. Nebraska, Texas, Colorado, and Washington each had 2 to 3 million acres, and South Dakota, California, Oklahoma, Oregon, and Idaho each had about 1 to $1\frac{1}{2}$ million acres. Each of the remaining States, had less than $\frac{1}{3}$ million acres, and Nevada had the lowest with only 14 thousand acres. Since the acreage of fallow has increased considerably, farmers apparently have felt that fallow is a worthwhile practice at least for their immediate benefit. Summer fallowing is generally used to promote greater and more stable production per harvested acre, and is sometimes used to aid in the control of weeds.

Fallow may be practiced in areas receiving as much as 28 inches of annual precipitation, as in southeastern Nebraska, but it is generally considered necessary only in regions receiving about 16 inches or less. The exception to this is in the central Plains region where fallow is reported necessary in areas receiving over 20 inches. Generally, wheat follows fallow except in California where spring barley is usually seeded in the fall.

Soil Water Storage

Increased soil-water storage is one of the primary purposes of summer fallowing. Ironically, however, summer fallow is an extremely inefficient method of storing soil water. In the northern Great Plains an average of only 19 percent of the precipitation received during the 21-month fallow period for spring wheat is stored in the soil. For annual cropping of spring wheat, an average of 32 percent of the precipitation received during the 9 months from harvest to seeding is stored. If water-storage efficiencies could be increased to 54 percent from harvest to seeding time in an annual cropping system, then as much water would be stored in the soil at seeding time as during a 21-month fallow period. Attaining this level of efficiency should not be beyond the realm of possibility.

The amount of water lost during the fallow period for spring wheat is generally more than the total annual precipitation. It is difficult to see how water can be considered a limiting factor in crop production when more than the equivalent of a year's precipitation is lost during a 21-month fallow period. Actually, water is not the limiting factor in crop production in many of the 17 Western States; rather, the limitation is the inability to efficiently store and use the water received.

Water-storage efficiencies are higher in the Northwest region, where precipitation is a more winter-type rainfall than in the Great Plains. At Tetonia, Idaho, for example, water-storage efficiency was 36 percent during fallow for spring wheat and was 85 percent from harvest to seeding for annual cropping.

For winter wheat, the longtime storage efficiencies of fallow were 18 percent in the northern and central Plains and 8 percent in the southern Plains. For annual cropping, the efficiency percentages were 27, 21, and 18, respectively. More recent information shows that, with better soil-management practices including subtillage, storage efficiencies of 28 percent have been attained on fallow at Sidney, Mont., 38 percent at three locations in the central Plains, and 15 percent at Bushland, Tex. Storage efficiencies on fallow in Utah were 37 percent, in Idaho 38 percent, and in California 17 percent. Data were not available for annual cropping in California.

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If water-storage efficiency for annual cropping at Bushland, Tex., could be increased from the present 22 percent up to 50 percent, then as much water would be stored in the soil at seeding time as during an entire fallow period.

From the results for water storage, it appears that sufficient precipitation is received from harvest to seeding time in an annual cropping system for winter wheat in the southern Plains and for spring wheat in the northern Plains so that, with improved water-conservation methods for annual cropping, water storage would equal or surpass that for fallow. At many other locations in the 17 Western States it would be nearly impossible to store as much water in an annual cropping system as in fallow, because of insufficient precipitation received from harvest to seeding time in the annual cropping system.

Wind Erosion

Wind erosion may be severe on fallow with the alternate fallow and spring wheat system commonly used in the northern Plains. Stubble-mulch tillage has aided in reducing the problem; but, by the second winter of the fallow period, generally sufficient crop residue does not remain to control erosion. Strip cropping, and barriers of trees, grass, sunflowers, corn, and flax are used to aid in reducing the soil-blowing problem.

Winter wheat is vulnerable to wind erosion in March and April of the wheat-growing season in the northern Plains. Stubble-mulch tillage is more effective in wind-erosion control for winter than for spring wheat. Winter wheat produces more straw and generally more straw is left at the end of the 14-month fallow period, which spans only one winter, than is left with spring wheat.

In the Central Plains, wind erosion occurs primarily after the wheat has been planted or during the dormant period, and not during the fallow period. When poor stands are obtained with continuous wheat, the erosion potential may be greater than with wheat planted on fallow since good stands are more likely to be obtained after fallow. One-wayed or plowed fallow land has 63 to 240 percent greater erodibility than land with stubble-mulch tillage. With present-day subsurface tillage equipment and drills capable of planting in residues, there is usually little excuse for excessive wind erosion in the central Plains. The exception would be after several successive years of drought when very little vegetative cover would be produced.

Wind erosion in the southern Great Plains is not so serious as in the past, because dryland fields are often interspersed with irrigated fields. However, stubble-mulch tillage should be practiced on the dryland fields. If irrigated acreage declines, or if droughts are extensive and prolonged, then wind erosion can be serious.

The acres damaged annually by wind erosion in the Great Plains area varies considerably (fig. 8.1). The acreage ranged from about 1 million in the 1942–43, 1943–44, and 1968–69 seasons to nearly 16 million in the 1954–55 season. As shown, considerably more acres were damaged in the fifties than in the "dirty thirties." Relatively few acres have been damaged annually since 1957.

In the Northwest region, wind erosion is of special concern in areas receiving less than 13 inches of precipitation. Stubble-mulch tillage has reduced the erosion problem, but wind erosion is still severe in eastern Washington and Oregon. Where the surface soil is pulverized, soil blowing may occur even with appreciable amounts of crop residues on the surface. Thus, for wind-erosion control, it is essential not only to maintain as much crop residues on the surface as possible but also to preserve a cloddy soil surface.

Wind erosion is generally not a problem in the Southwest region except in localized areas of southwestern and west-central California, and during some years in San Juan County, Utah. Strip cropping has been effective in reducing wind erosion in California, and soil ridging is sometimes practiced in Utah to control wind erosion over winter.

Water Erosion

Water erosion is a problem on fallow in nearly all regions, ranging from slight to severe. In the northern Great Plains erosion occurs from both snowmelt and torrential rains. Snow is generally blown from bare fallow fields, but runoff from snow collected in adjacent stubble fields or in barriers often moves across fallow fields and causes serious erosion problems. Erosion due to thunderstorms is usually localized.

In the central Great Plains, water erosion is not a major problem, but where it occurs it is most serious during the fallow period.

In the southern Great Plains, water erosion is

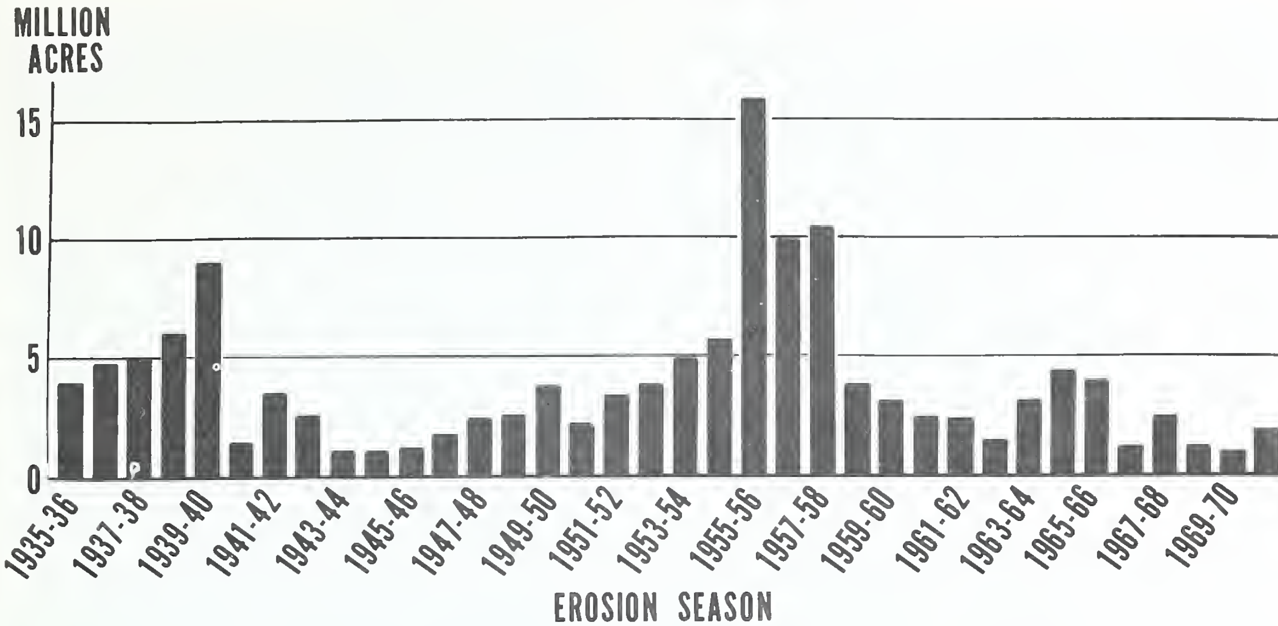

FIGURE 8.1.—Acres of land damaged annually by wind erosion in the Great Plains. (Data for 1943–44 through 1952–53 from Great Plains Council reports; other data from Soil Conservation Service reports.)

not a serious problem on the High Plains of Texas and the Oklahoma Panhandle. Average runoff from a level-terraced area at Bushland, Tex., for example, was 1 inch per year. However, erosion is a serious problem on the Rolling Red Plains and Reddish Prairies.

In the Northwest region, water erosion is severe on fields seeded to wheat after summer fallow where plant residues have been buried or destroyed and soil cloddiness eliminated by numerous tillage operations. The problem is particularly severe in the Palouse area. Rainfall or snowmelt on soils frozen to a depth of 1 inch or more on steep slopes cause extreme erosion. Also, severe soil erosion often occurs as a result of intermittent to nearly continuous rainfall for several days on unfrozen soil, although the intensity may seldom exceed 0.1 inch per hour even for short periods.

In the Southwest region, water erosion is severe on fallow in California. Soil losses have ranged from 17 to 21 tons annually without straw mulch and only 1 ton with straw mulch. Water erosion may occur in Utah from high-intensity summer storms and from rain or snowmelt on frozen soil; however, the problem is not considered severe.

In all regions, water erosion can be materially reduced by leaving as much crop residue on the soil surface as possible by stubble-mulch tillage. Other measures that can be used for water-erosion control are standard terraces, flat channel terraces, level benches, and contour farming.

Summer-fallow land is apparently as susceptible and often more susceptible to wind and water erosion than other cropping systems; therefore, from the standpoint of erosion, fallow cannot be considered a soil-conserving practice.

Soil Fertility

Soil fertility, as measured by total nitrogen and organic carbon, generally declines more under fallow than under continuous cropping. The differences in losses between the two treatments, however, usually have not been great. For example, the average loss of total nitrogen from the surface soil after 30 or more years of cropping in the northern, central, and southern Plains was 29, 18, and 47 percent, respectively, for continuous cropping and 37, 27, and 49 percent for alternate small grains and fallow compared with virgin sod. Organic carbon losses were usually slightly higher than total nitrogen losses.

Data comparing the effect of continuous cropping and alternate cropping and fallow on the total nitrogen and organic carbon content of soils of the Northwest and Southwest are limited. However, results of a study at Pullman, Wash., showed that the surface foot of soil under continuous wheat without soil amendments lost only 1 percent of the total N content in 25 years but alternate wheat and fallow lost 12 percent. The figures for organic C were +1 and −8 percent, respectively. Straw, straw plus ammonium sulphate, and manure reduced the losses.

At Nephi, Utah, the 3-foot soil increment lost 4 percent of the total N content under continuous wheat and 8 percent under alternate wheat and fallow during a 25-year period. However, gains of 3 and 5 percent, respectively, were recorded for organic C.

Losses of soil nitrogen from a wheat-fallow system in Washington and Oregon have ranged from 11 to 33 percent of the original N content. In southern California, losses of soil nitrogen after 70 years of alternate cropping and fallowing have ranged from 29 to 42 percent.

Nitrate N is usually higher at wheat-seeding time under fallow than under continuous cropping. In some of the higher precipitation areas where fallow is being practiced, the benefits derived from fallow may be due more to the higher soil nitrate content than to greater soil-water storage.

The available information on the effect of alternate cropping and fallowing and continuous cropping on the total P content of soils indicates there is little difference between the two cropping systems in the Great Plains. However, results from a study in Utah indicated losses of total P were about 38 percent greater from alternate crop and fallow than from continuous cropping.

Available soil P has generally been higher under the wheat-fallow system than under annual cropping in the Great Plains. However, the available P content could not be related to cropping system in California. Surface soils in the Northwest are generally well supplied with available phosphorus, but badly eroded hilltops are usually deficient.

Sulfur is known to be deficient for alfalfa in eastern Washington and northern Idaho. With the use of chemical fertilizers for supplying N, S has become deficient for cereals under some conditions in eastern Washington, northeastern Oregon, and northern Idaho.

Although fallow increases the availability of some nutrients, total nutrient losses from fallow are usually as high as, and often higher than, from some other cropping practices. Therefore, as judged by changes in soil fertility, summer fallow cannot be considered a soil-conserving practice.

Crop Yields

Crop yields per planted or harvested acre usually are higher after summer fallow than in other cropping systems, where inadequate water and available nitrogen and where certain weeds limit production. But it should be remembered that it takes 2 years to produce one crop with the fallow-crop system. In the northern Plains, longtime research results without fertilizers showed fallow increased spring wheat yields 18 to 95 percent over those of wheat after wheat and 3 to 32 percent over those of wheat after corn. The smaller increase from fallow over cornland indicates that cornland is a good substitute for fallow for wheat production. The corn produced would more than offset the value of the loss in wheat production.

Short-time results show that without fertilizers, fallow increased yields 4 to 60 percent compared with annual cropping. Where fertilizers were not applied to fallow but were applied to annual cropping, the increase from fallow ranged from a −24 to 26 percent; this indicates that the benefit from fallow in some cases was due to release of available nitrogen and not to increased soil-water storage. Where fertilizers were applied to fallow and to annually cropped land, the increases from fallow ranged from 8 to 56 percent, or about the same as without fertilizer.

The largest acreage of winter wheat in the northern Great Plains is in Montana followed by that in South Dakota and Wyoming. Only a small acreage is grown in North Dakota. Longtime research results before 1951 showed fallow increased winter wheat yields in the northern Plains 156 percent over continuous cropping. U.S. Department of Agriculture Statistical Reporting Service data show that winter-wheat yields in Montana averaged 16.5 bushels per acre for the period 1929 to 1951 compared with 24.9 bushels per acre for the period 1952 to 1970. Climatic conditions were similar for the two periods. The 51 percent increase in grain yields since 1952 reflects the overall influence of improved technology in agriculture, such as better tillage methods and crop varieties, weedicides, fertilizer, and seed treatments.

Trials show that without fertilization continuous winter wheat averaged 12 bushels per acre and wheat after fallow averaged 24 bushels per acre (100 percent increase). With adequate fertilization, the yields were 23 and 30 bushels per acre, respectively, or 30 percent increase. However, good or adequate stands of winter wheat cannot always be obtained under continuous cropping, because of inadequate water at seeding time in the fall. It is better for wheat to follow corn where yields are reduced only 3 to 5 bushels per acre compared with wheat on fallow. Or, a rotation of winter wheat-spring barley-fallow is excellent, because barley in the rotation aids in controlling downy bromegrass. Wheat yields have averaged 39 bushels per acre in a wheat-barley-fallow rotation compared with 32 bushels in a wheat-fallow rotation.

At three experimental stations in the central Great Plains (Akron, Colo., North Platte, Nebr., and Colby, Kans.), continuously cropped winter wheat averaged 9.9 bushels per acre and wheat on fallow averaged 24.0 bushels per acre, or 142 percent increase. The large increase in winter wheat yields from fallow in some sections of the central Great Plains as well as in the northern Great Plains is due, in part, to the comparatively short period of time and to the small amount of precipitation for soil-water storage from harvest to seeding time in the annual cropping system. At Hays, Kans., with higher precipitation, the yields were 14.4 and 22.6 bushels per acre, respectively, or 57 percent increase. In recent years, marked improvement has been reported in yields of winter wheat on fallow in the central Plains, but little improvement has been reported in yields of annually cropped wheat. The increased yield on fallow was attributed not only to improved water-storage efficiency on fallow but also to better planting equipment and improved wheat varieties.

In the southern Plains, there is more time for water storage between harvest and seeding time in an annual cropping system, and the yield advantage of fallow is not so great as farther north. At Bushland, Tex., continuous cropping produced 9.6 bushels per acre and wheat on fallow produced 15.0 bushels per acre, or a 56 percent increase. In another study, continuous wheat produced 10.4 bushels per acre, a 3-year rotation of fallow-wheat-sorghum produced 13.0 bushels, and a 2-year rotation of wheat-fallow produced 14.7 bushels per acre. Low fertility is not a problem in the High Plains; hence, crops respond very little to fertilizer. In the Rolling Red Plains and Reddish Prairies, low fertility rather than limited water often restricts yields. At Lawton, Okla., continuous wheat yielded 13.8 bushels per acre and fallow 19.4 bushels, or a 41 percent increase with fallow.

The response that farmers are receiving from fallow was estimated by calculating the percentage yield increases from data provided by the Statistical Reporting Service [2] for every county in the Great Plains where sufficient data were available. Counties with less than 3 years of data were omitted. Similar data were available for only a few of the remaining 17 Western States and the calculations were therefore limited to only nine of the Great Plains States. Data are shown in table 8.1.

The percentage spring wheat yield increases from fallow by counties are presented in figure 8.2. Continuous wheat produced more than wheat on fallow only in Golden Valley County, Mont. Counties with 1 to 25 percent increase in yield from fallow were found along the eastern border of North and South Dakota, southwestern South Dakota, western Montana, and a few other scattered areas.

Most of the counties in all three States showed a 26 to 50 percent increase. Fifty-one to seventy-five percent increases occurred primarily in northern North Dakota and southeastern and northwestern Montana. Sweet Grass County, Mont., had an increase of 77 percent, which was the only county in the three States with an increase of more than 75 percent.

The results for winter wheat (figs. 8.3.1 to 8.3.3) are much more variable from county to county than for spring wheat. Increases of over 100 percent were attained in some counties. A few scattered counties in the Oklahoma and Texas Panhandles and sizable numbers of counties in western Kansas and Nebraska, eastern Colorado and Wyoming, south-central South Dakota, and southeastern and north-central Montana, had more than 50 percent increase.

The calculated percentage increases were generally lower than those reported from experiment stations in the respective counties, because, among other reasons, farmers may have been inclined to annually crop their more favorable land and because there is an imbalance in acreage between the two cropping

[2] United States Department of Agriculture. Statistical Reporting Service. 1946–70. Agricultural Statistics.

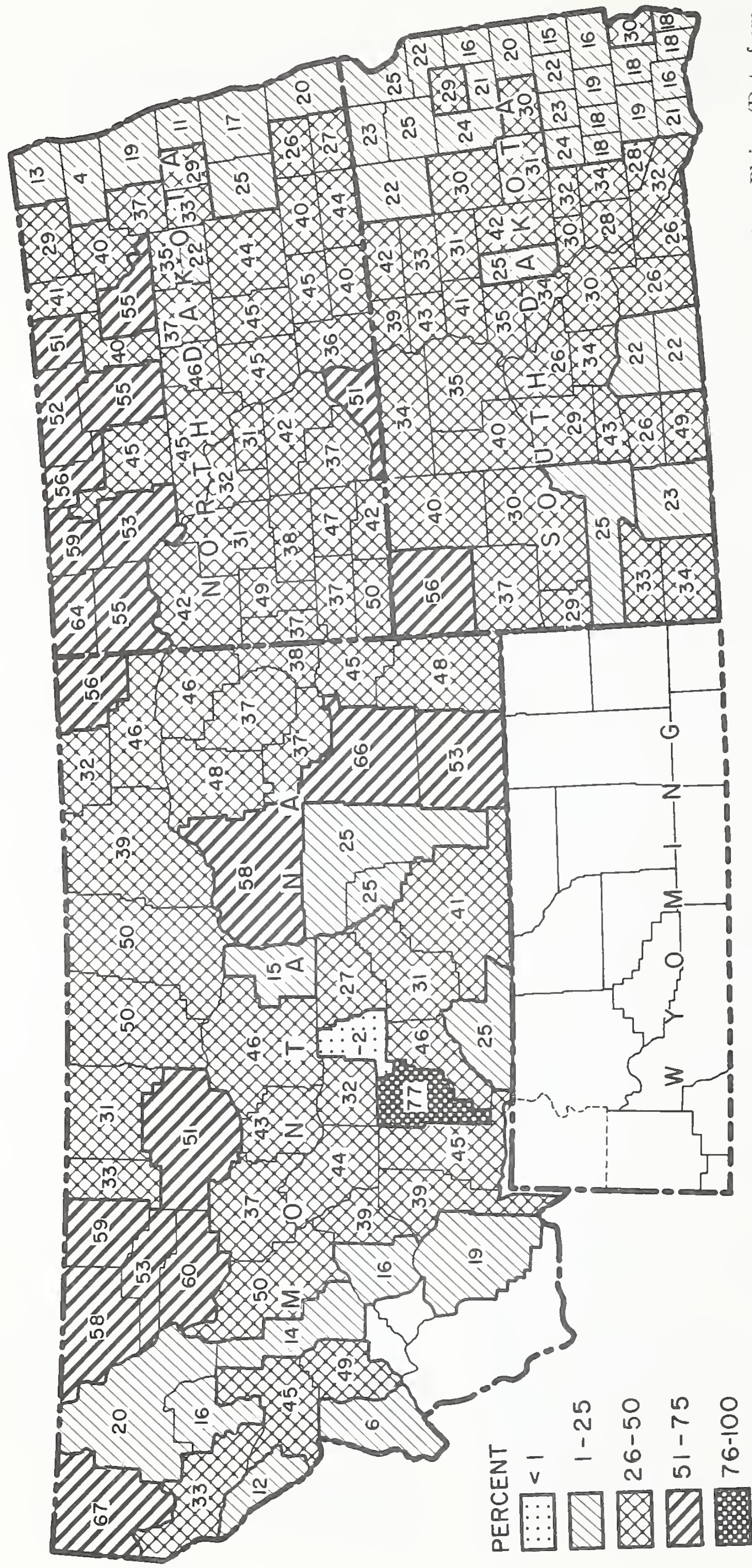

FIGURE 8.2.—Percentage increase in spring wheat yields per planted acre on fallow over yields on annually cropped land in the northern Great Plains. (Data from the USDA Statistical Reporting Service.)

TABLE 8.1.—*Average acreage of wheat planted on fallow and continuously cropped and average yield for each of nine Great Plains States*

[Data obtained from the U.S. Department of Agricultural Statistical Reporting Service]

State	Wheat type	Period	Number of years	Acres planted— On fallow	Continuous	Yield [1]
						Bu./A.
Montana	Spring	1960–69	10	1,542,290	66,680	18.7
	Winter	1960–69	10	2,325,490	31,380	24.0
North Dakota	Spring	[2] 1956–69	13	3,359,438	1,683,962	20.4
	Winter	1964–69	6	68,133	8,700	20.2
South Dakota	Spring	1960–69	10	570,484	1,076,396	17.1
	Winter	1960–69	10	645,502	76,698	21.4
Wyoming	All	1964–68	5	278,330	9,190	19.1
Nebraska	Winter	1946–69	24	1,868,770	1,926,231	21.9
Colorado	do	1959–69	11	2,643,836	86,255	14.2
Kansas	do	[3] 1954–70	16	4,749,938	5,806,188	20.6
Oklahoma	do	1964–69	6	670,367	3,809,483	19.3
Texas	do	1968–70	3	616,200	1,752,483	12.3

[1] Weighted average, based on acreage and yield of wheat on fallow and continuous cropping per planted acre.
[2] 1963 missing.
[3] 1956 missing.

systems in many of the counties (fig. 8.4). The upper figure in each county indicates the thousands of acres seeded to wheat, including hard red winter, hard red spring, and durum, planted on fallow in 1968—the most recent year for which complete data were available. The lower figure indicates thousands of acres annually cropped. Counties with less than 500 acres were recorded as zero or left blank.[3]

The figure shows the high proportion of wheat seeded on fallow in the drier areas and the small acreage annually cropped. The acreage and proportion annually cropped generally increases from west to east, with increasing precipitation. However, in northeastern North Dakota, the acreage of wheat planted on fallow remains higher than that annually cropped.

In the Northwest region of the United States, fallow is generally considered necessary in areas with less than 15 inches of precipitation. However, with proper fertilization, fallow should be necessary only in areas with less than 13 inches. Sixty pounds of nitrogen applied per acre to both fallow and annual cropping reduced fallow wheat yield increase from 121 to 45 percent at Pullman, Wash., from 101 to 21 percent at Lacrosse, Wash., and from 268 to 88 percent at Pendleton, Oreg. Smaller increases from fertilizer occurred at Moro, Oreg., and Tetonia, Idaho.

Early results from California in the Southwest region showed that fallow increased wheat yields about 210 percent over continuous wheat. Recent information indicates that the yield increase from fallow may be reduced and that production is more stable with the application of fertilizer and by retaining runoff. With fertilizers and runoff retention, barley yields have been only about 25 percent higher on fallow than on annually cropped land. In Utah, longtime results indicate yields after fallow were twice those from annually cropped land. No data were available comparing the effect of fertilizers on yields after fallow with those from continuous cropping.

[3] See footnote 2, p. 153.

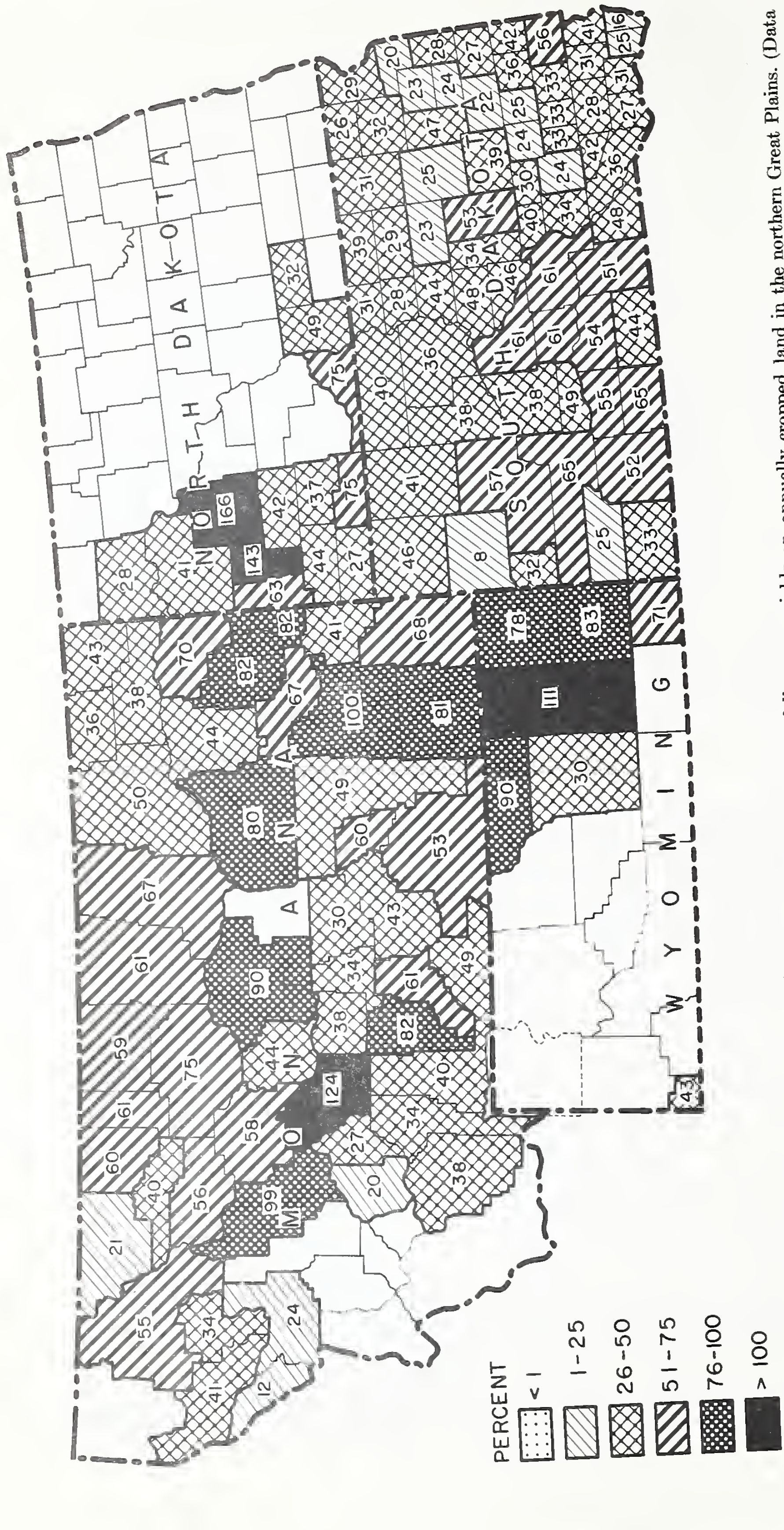

FIGURE 8.3.1.—Percentage increase in winter wheat yields per planted acre on fallow over yields on annually cropped land in the northern Great Plains. (Data from the USDA Statistical Reporting Service.)

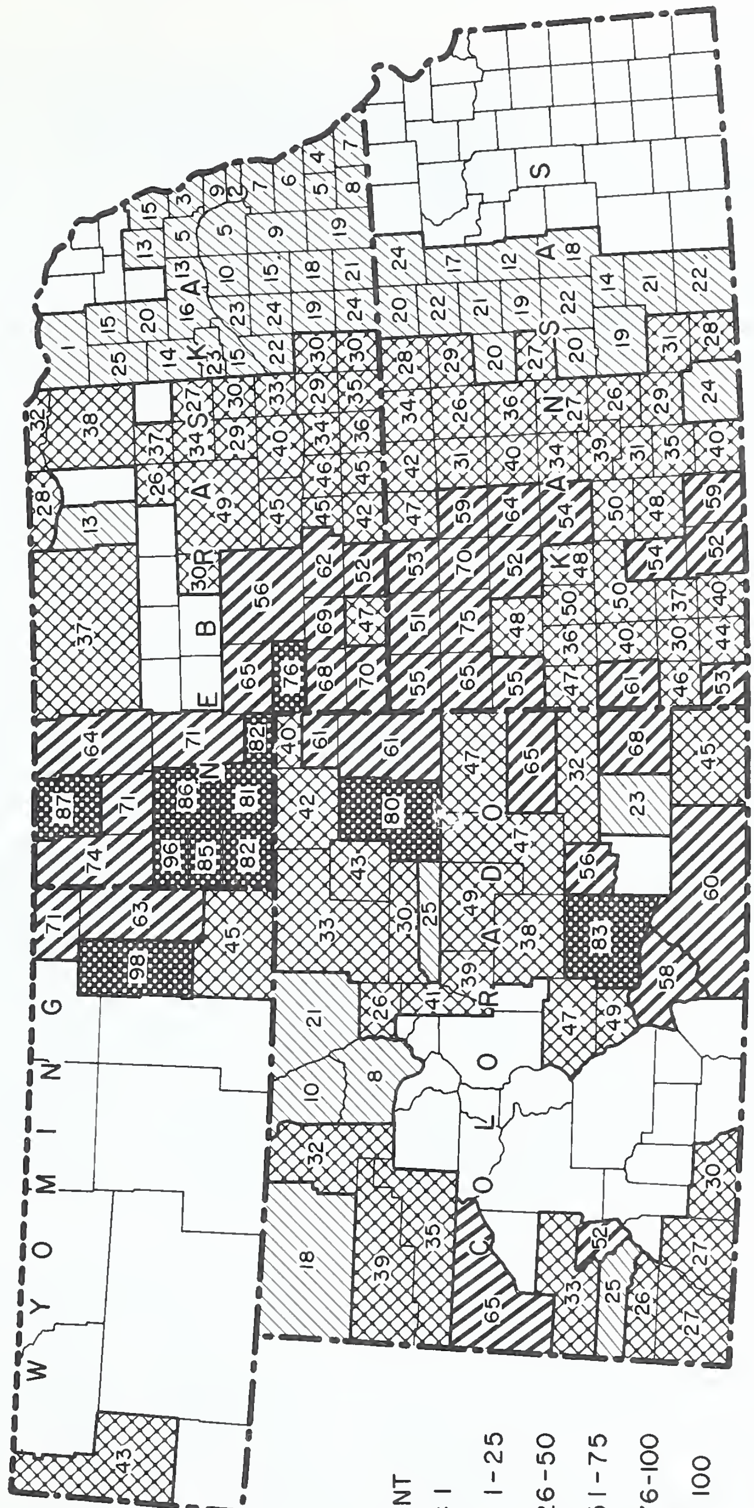

FIGURE 8.3.2.—Percentage increase in winter wheat yields per planted acre on fallow over yields on annually cropped land in the central Great Plains. (Data from the USDA Statistical Reporting Service.)

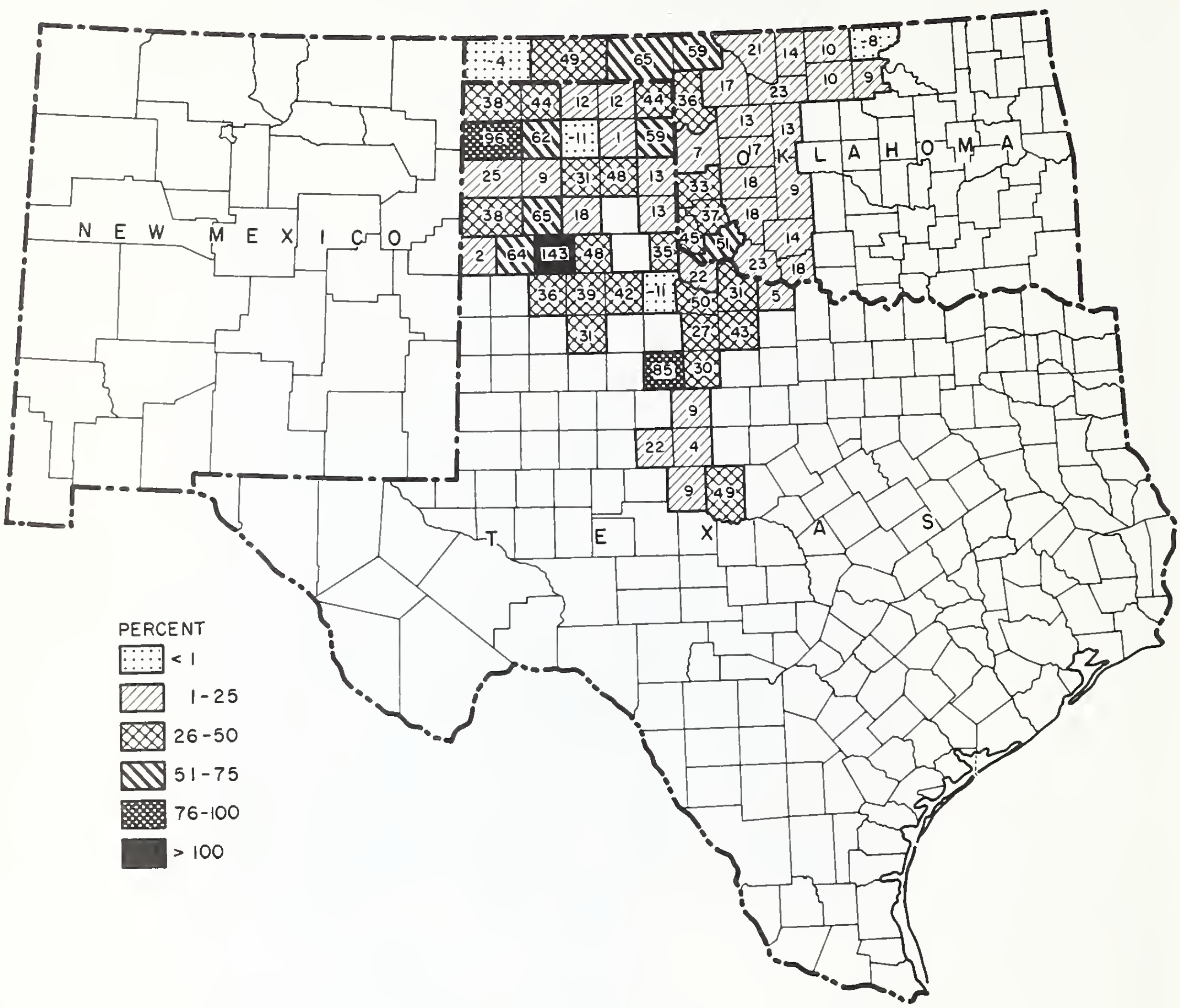

FIGURE 8.3.3.—Percentage increase in winter wheat yields per planted acre on fallow over yields on annually cropped land in the southern Great Plains. (Data from the USDA Statistical Reporting Service.)

Water-Use Efficiency

Water-use efficiency is generally higher in a continuous cropping system than in a crop-fallow system. Water-use efficiency was calculated by dividing the bushels of grain produced by the inches of precipitation received from harvest to harvest. For annual cropping, annual precipitation was used; and for the crop-fallow system, the 2-year total precipitation was used. The water-use efficiency values ranged from 0.53 bushel per inch in the central Plains for annual cropping to 2.00 bushels in the Northwest region. The values for the crop-fallow system ranged from 0.66 in the central Plains to 1.61 in the Northwest region. In some cases, however, water-use efficiency of the crop-fallow system in the central Plains has been increased to over 1.00. The central Plains was the only region where water-use efficiency for the crop-fallow system exceeded that of the annually cropped system.

Crop Quality

Crop quality as measured by protein content and test weight of grain is nearly always higher after

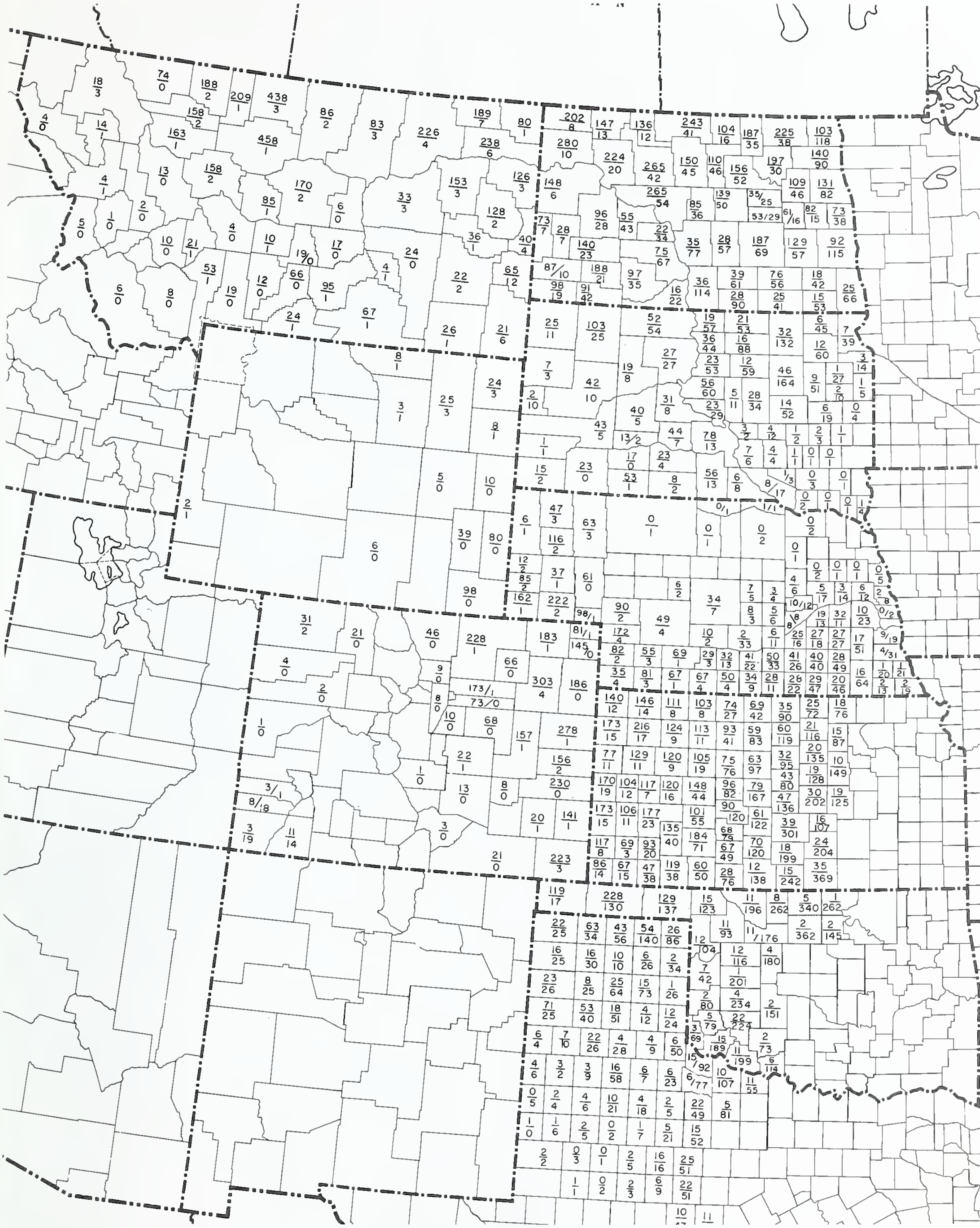

FIGURE 8.4.—Thousands of acres of wheat (hard red winter, hard red spring, and durum) planted on fallow (upper figure) and annually cropped (lower figure) in each county in the Great Plains in 1968. Counties with less than 500 acres were recorded as zero or left blank. (Data from the USDA Statistical Reporting Service.)

fallow than from annual cropping. Apparently the additional nitrate released by fallow is sufficient to supply nitrogen for increase in yield as well as for increase in protein content. Test weight of spring wheat grain was usually higher in Montana from annual cropping than from a wheat-fallow system, but the differences were small. At other reporting locations, test weights were higher after fallow than from annual cropping.

Two general conclusions can be drawn from the foregoing:

(a) In view of the erosion and the fertility-decline problems associated with fallow, fallow cannot be considered a soil-conserving practice. In fact, fallow is as soil depleting as most other cropping systems, or even more so.

(b) Apparently a large number of acres presently being fallowed cannot be justified from the standpoint of yield increase alone.

Probably the first question that arises then is: Should a concerted effort be made to reduce the acreage of fallow? If the answer to this first question is yes, then the second question is: Where? This is not an easy question to answer, particularly in a region where extreme variation in climate is the rule rather than the exception.

It would be helpful to know how much fallow should increase yields over other cropping systems for fallow to be considered economical. Analyses have been made regarding the immediate economic benefit to the farmer, but they have not included the cost the public is paying for increased erosion from fallow in many areas. Such a cost would be difficult to obtain. It should include not only the cost of losing soil from the fields but also the cost of removing soil from roads, ditches and drainage channels, the cost of highway accidents and sometimes loss of life because of dust blowing across highways, and the cost of removal of sediment from ponds and reservoirs or the cost of new ones because the old ones are filled. Also to be considered are the health problems associated with dust polluting the air, the psychological problems associated with the absence of a more aesthetic landscape, and the wildlife problems associated with reduced habitat acreage.

Proper fertilization has reduced the yield advantage of fallow and has narrowed the zone where fallow is essential for crop production. Crop substitutes for fallow can be and are being used in some areas. For example, in some areas of the Northwest region, peas are substituted for fallow in a rotation with wheat. Under some conditions, corn or sorghum can be substituted for fallow in the northern Plains with only small reduction in spring wheat yields.

A rotation of fallow, winter wheat, and sorghum is being used in the central and southern Plains and a rotation of fallow, winter wheat, and spring barley is being used in the northern Plains, but in both instances fallow is considered necessary. However, only one-third instead of one-half of the land is in fallow.

Perhaps the one thing that would help the most in reducing the acreage of fallow would be the development of an economical method of controlling water loss by evaporation. A number of methods have been developed, but none has proved economical.

One of the primary questions that needs to be answered regarding summer fallowing is: Are there better uses for the 37 million acres of good, cultivated land lying fallow each year in the 17 Western States, not only from the standpoint of present needs but also from the standpoint of needs of future generations?

With our present knowledge, the acreage of fallow could be reduced considerably; if better water-conserving practices were developed, the acreage could be reduced still further. If the acreage of fallow were reduced, then that not needed for crop production could be seeded to grass for livestock production, game refuges, or recreational areas and parks and the soil held in place and preserved for posterity.

However, some means of reimbursing the land owner would be needed. If such a program were followed, the food and fiber needs of the populace would still be met as well as the needs for recreational areas and a more healthful environment.

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